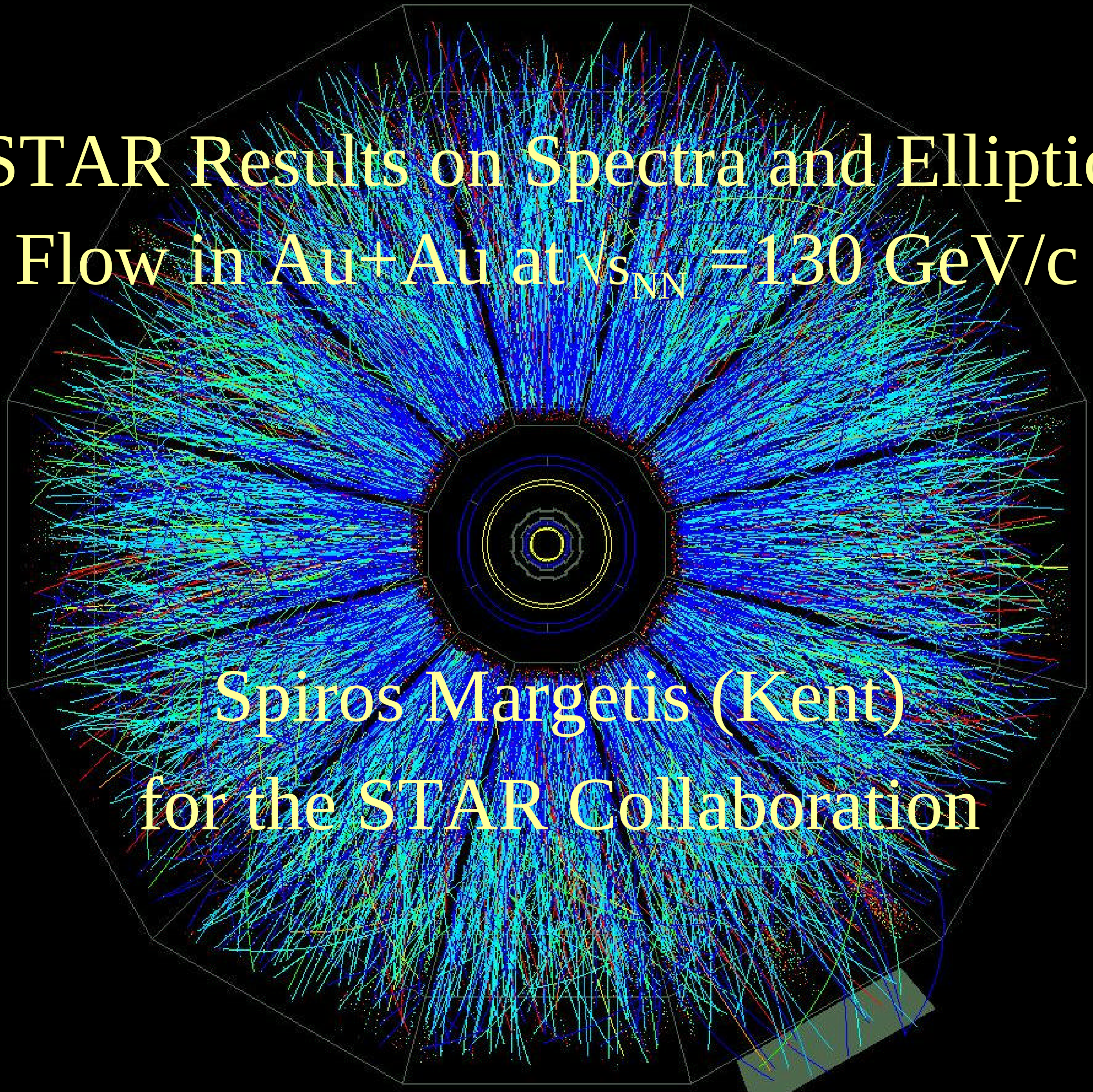
STAR Results on Spectra and Elliptic Flow in Au+Au at $\sqrt{s_{NN}}$ =130 GeV/c

Spiros Margetis (Kent)

for the STAR Collaboration

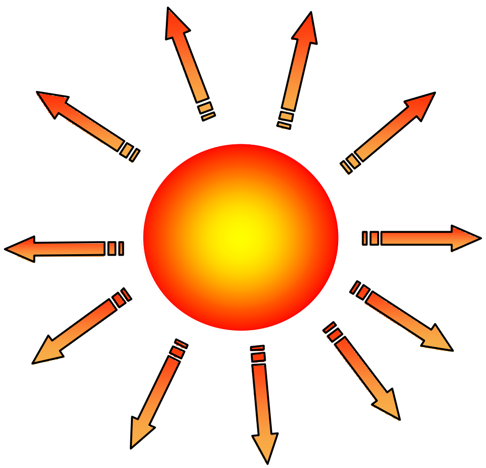


Overview

- Introduction
- Particle spectra
  - Radial flow
- Elliptic flow measurements in STAR
  - Elliptic flow systematics of negative hadrons
  - Elliptic flow for identified particles
- Summary
- Particle ratios -> Next speaker

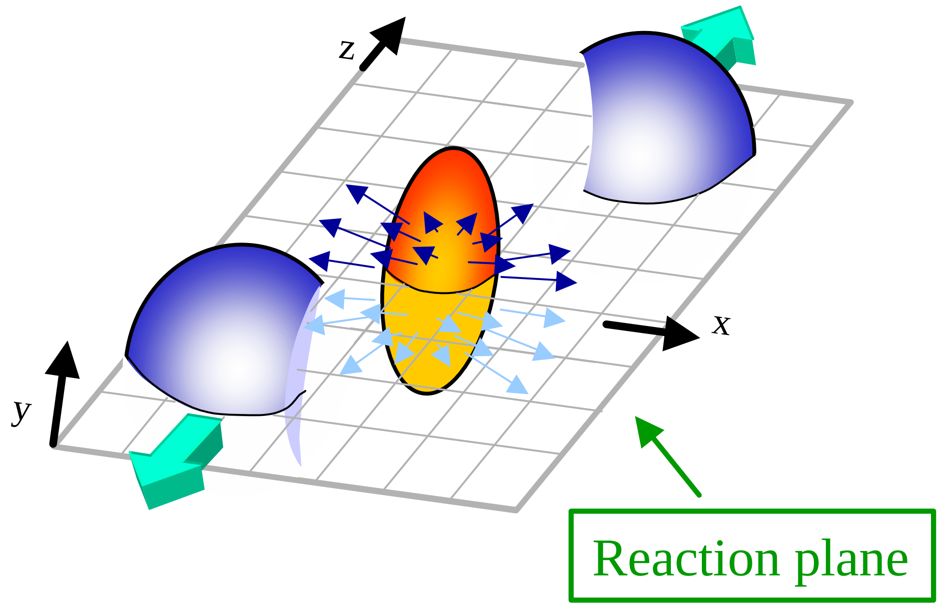
Geometry of Heavy Ion Collisions

Central Collisions



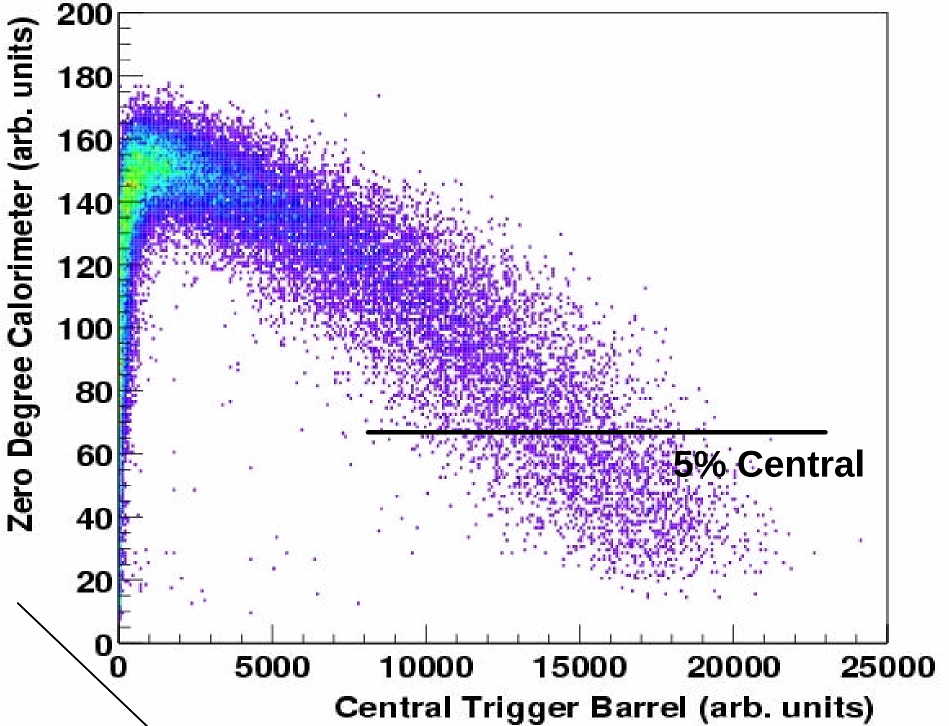
Radial Flow (Slope systematics)

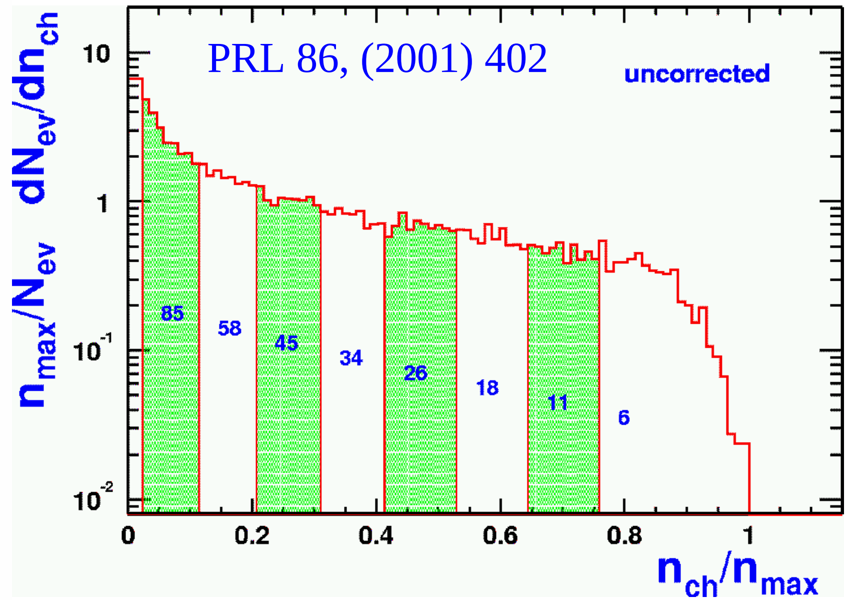
Non-central Collisions



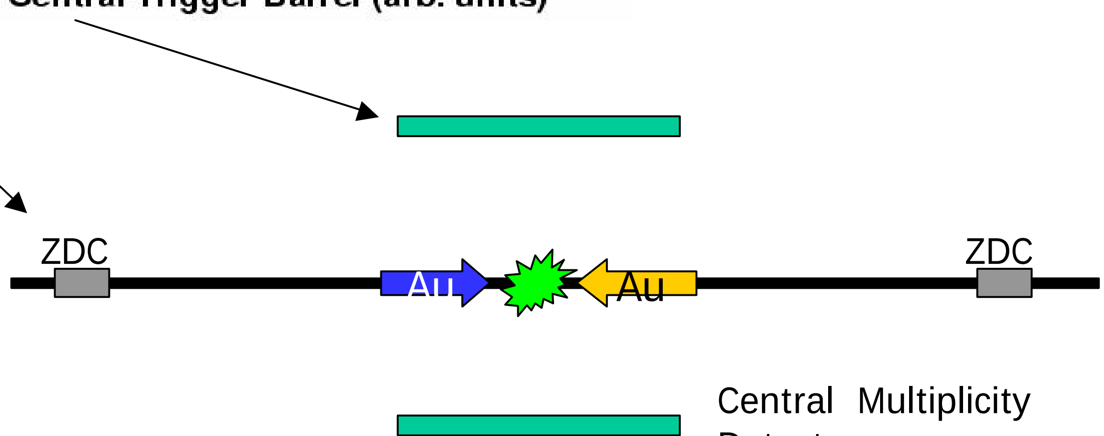
Elliptic Flow

Event (Centrality) Selection





n_{ch} = primary tracks in $|\eta| < 0.75$



Central Multiplicity Detectors

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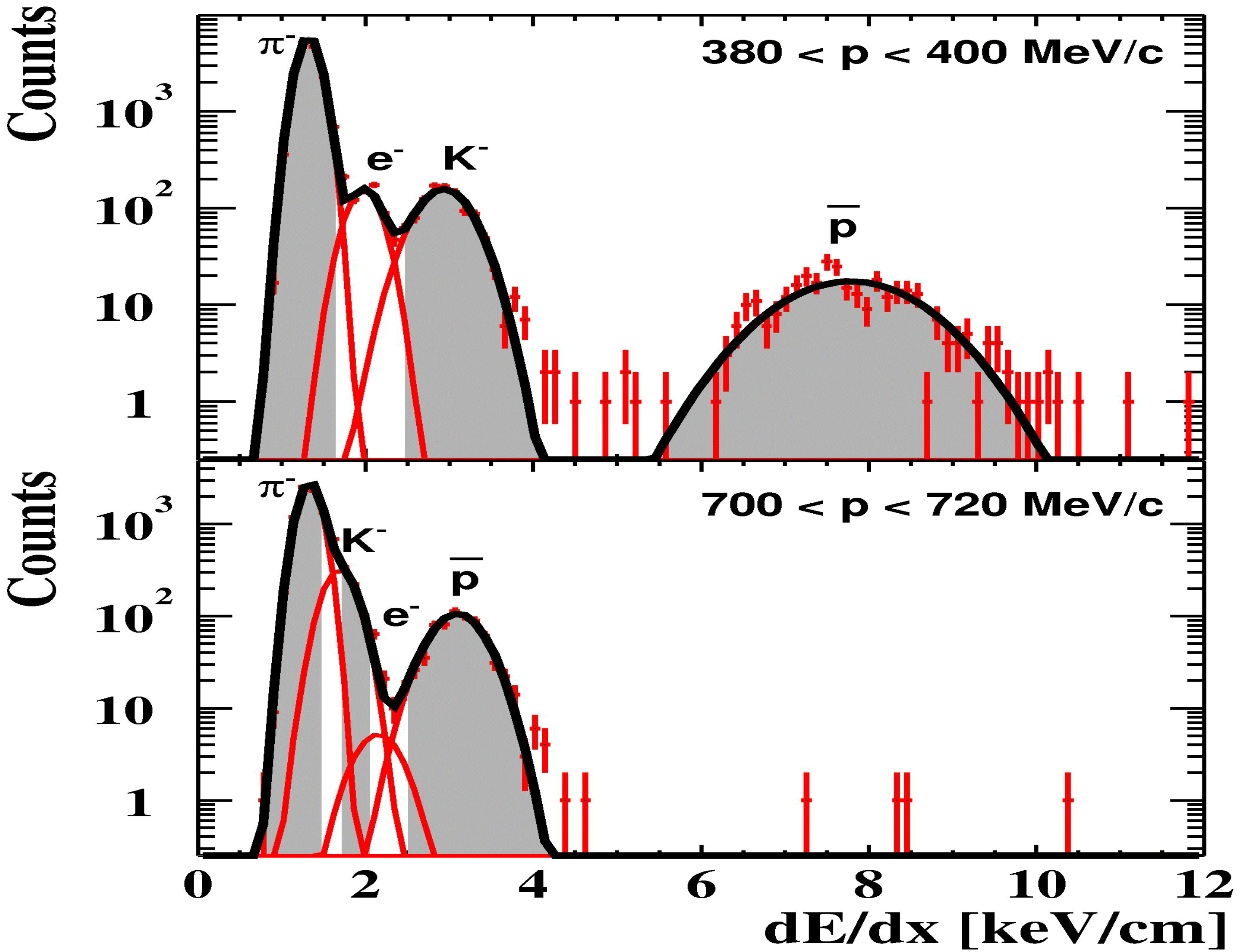
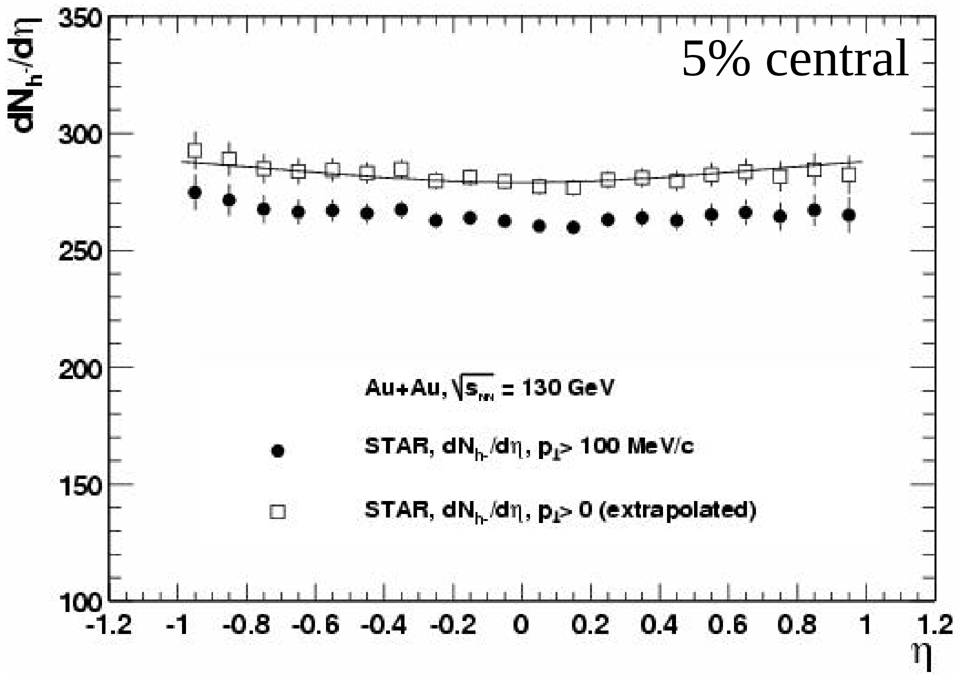
PID via dE/dx

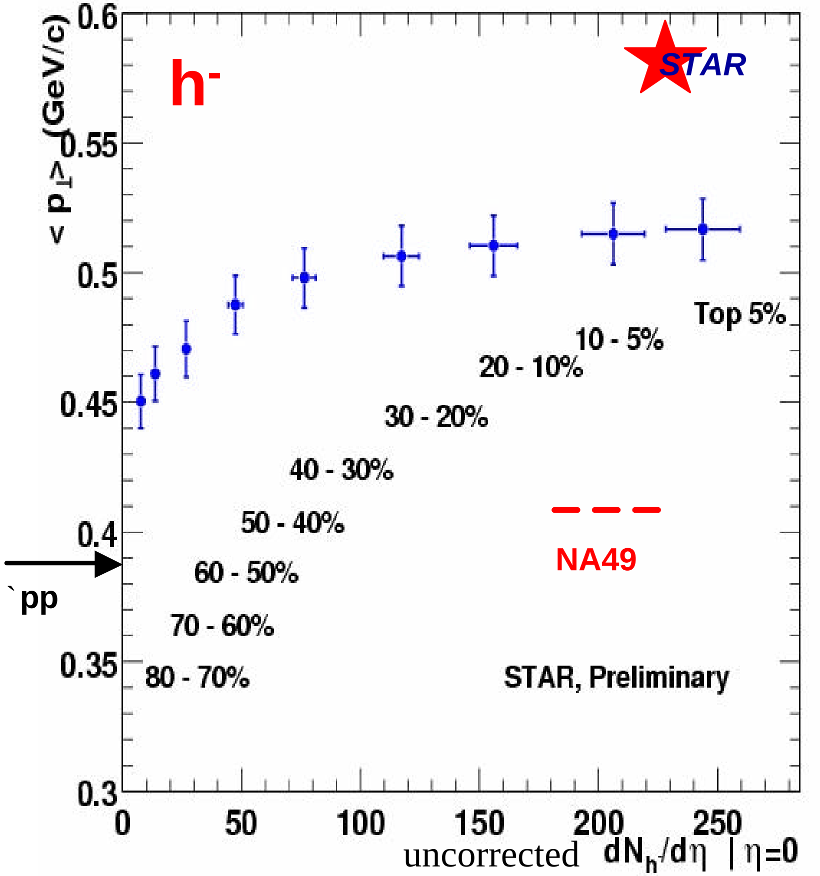


Counts
380 < p < 400 MeV/c
700 < p < 720 MeV/c
π^-
e^-
K^-
$\bar{p}$
1
10
10^2
10^3
0
2
4
6
8
10
12
dE/dx [keV/cm]

h^- : Eta Distribution and $\langle p_t \rangle$ vs. Centrality

PRL accepted



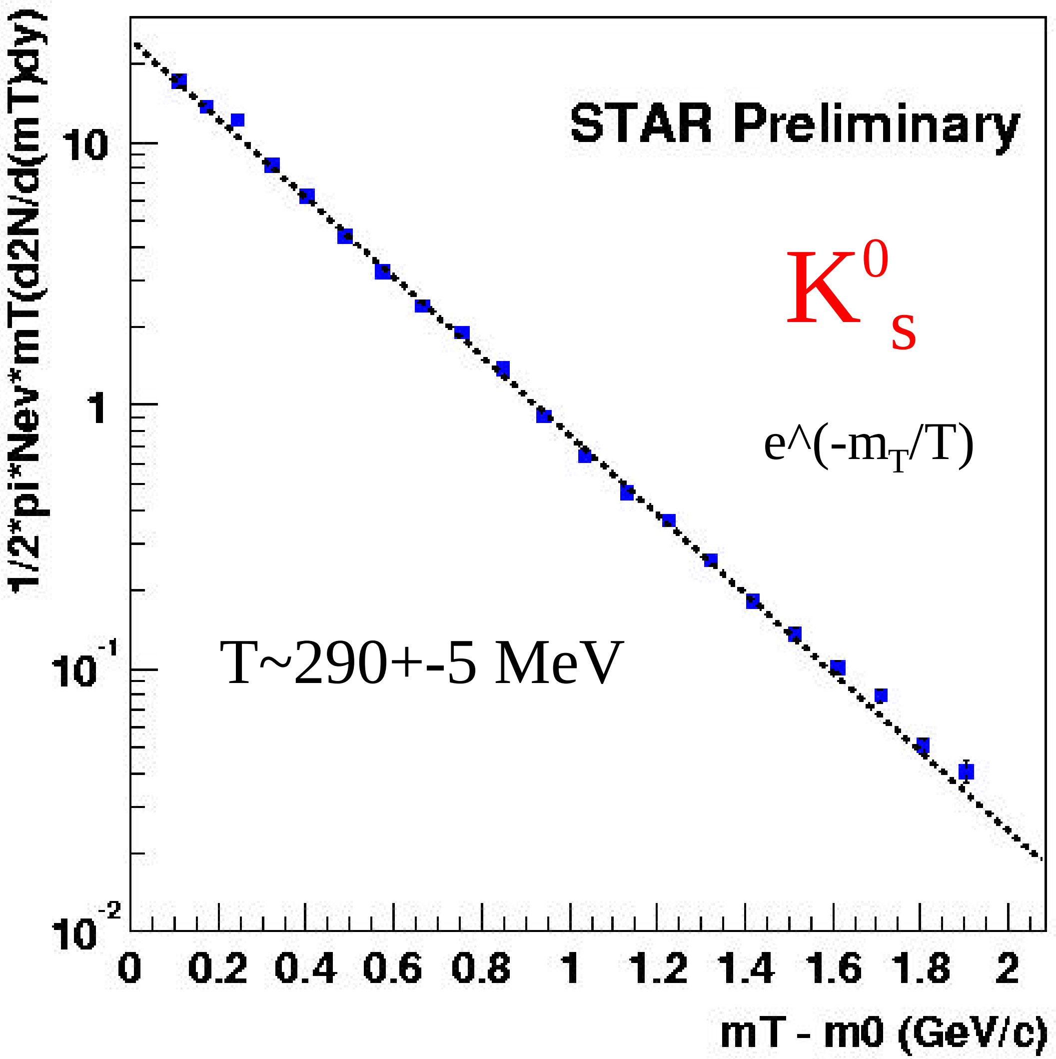


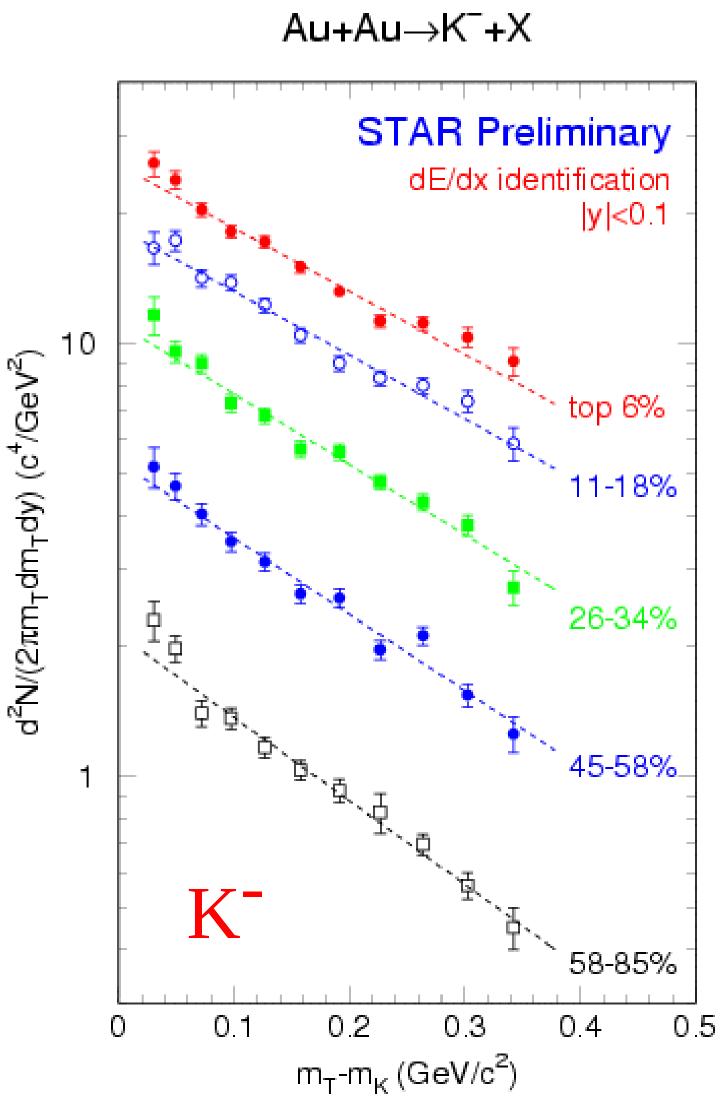
Hydro, long. boost invariant picture compatible

dN/dη higher than scaled pp

$\langle p_t \rangle$ increases with centrality

For central collisions higher than in min. bias pp collisions @ $\sqrt{s}$ = 1.8 TeV (CDF)

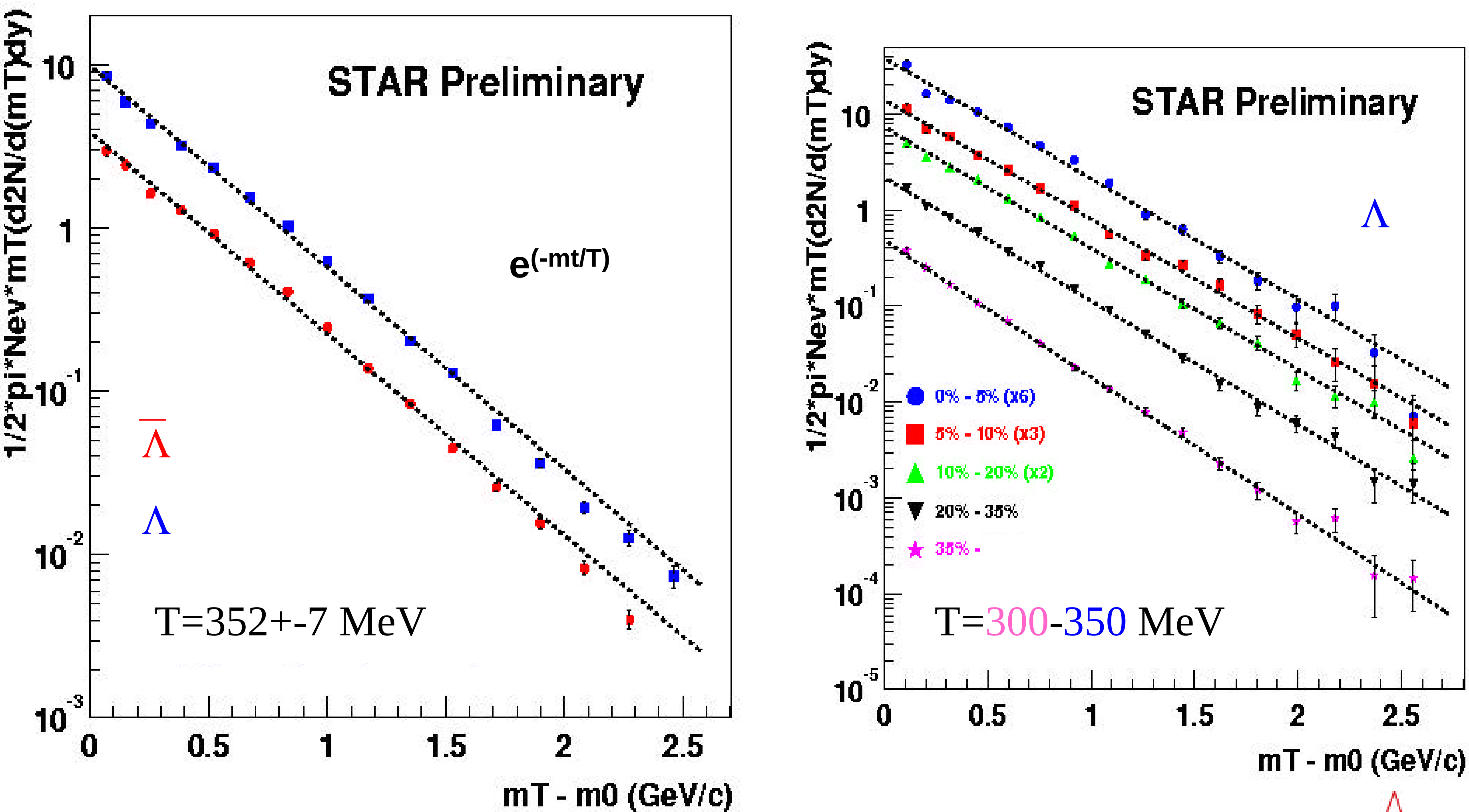




(T_π~190-200 MeV)

Inverse slope systematics Λ

Note spectra are not *feed-down* corrected



Some indication that one slope fit is not appropriate at low and high m_t

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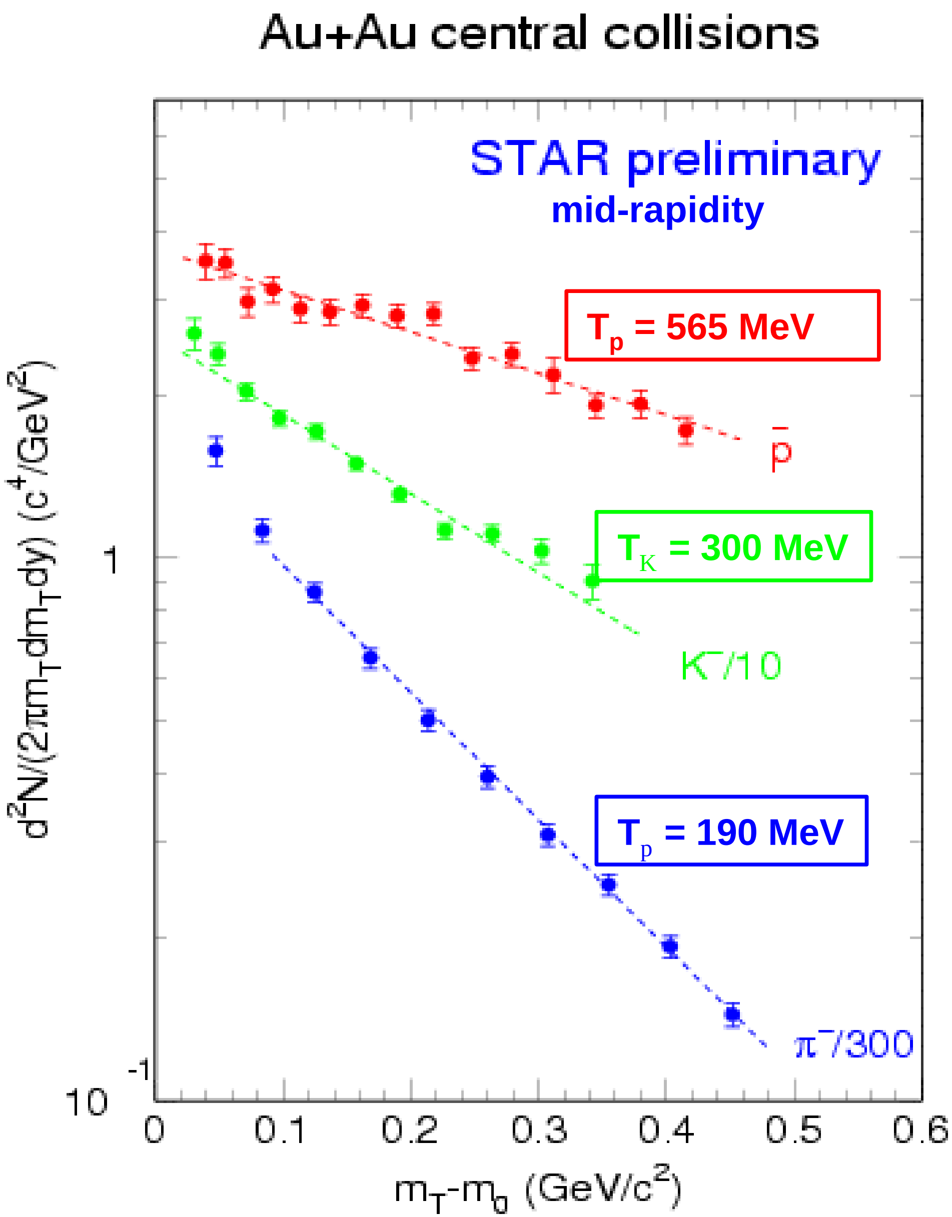
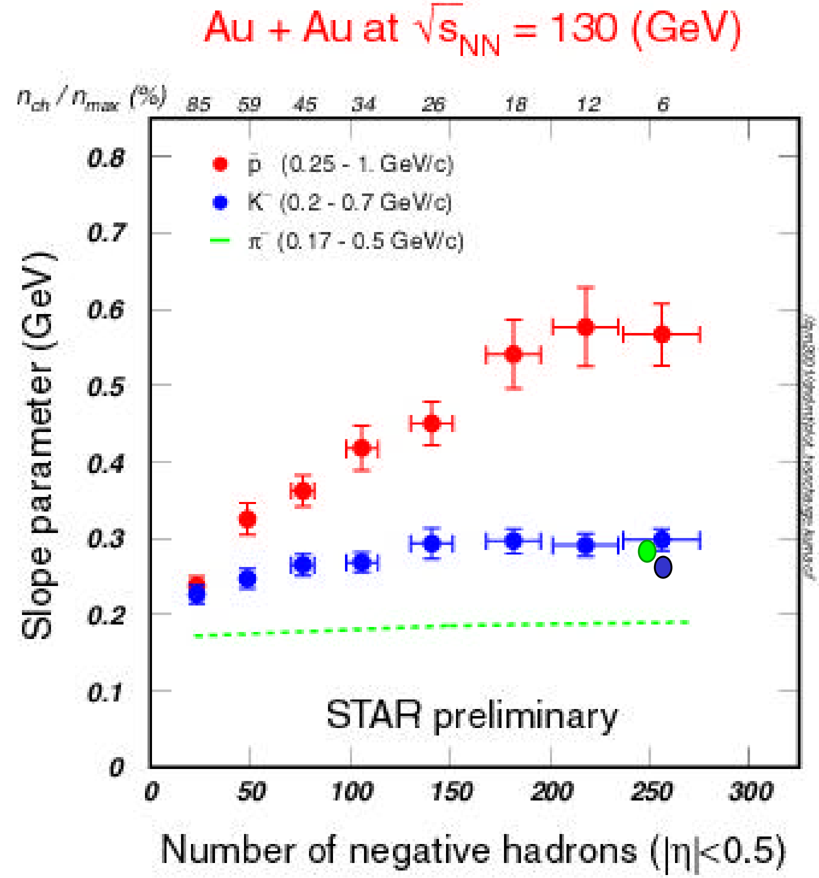
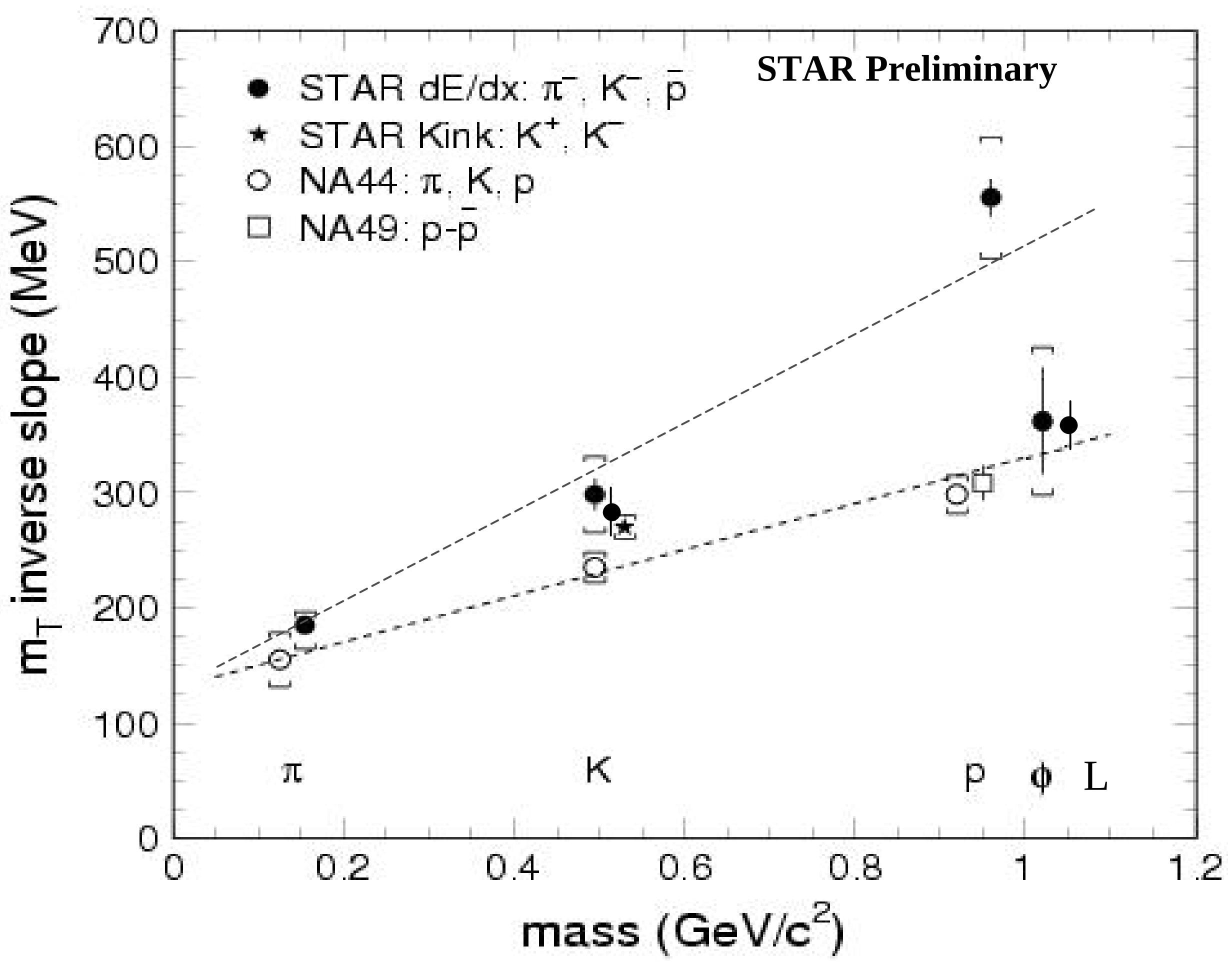
m_t slopes vs. Centrality





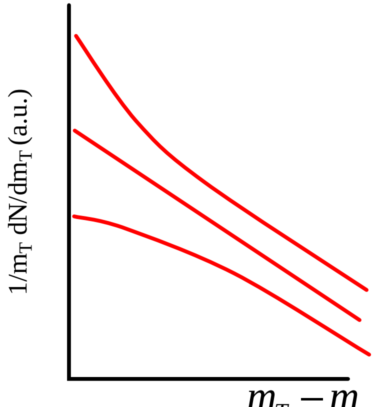
- **Increase with collision centrality**
- **® consistent with radial flow.**

Mass dependence of m_T slope - Radial Flow



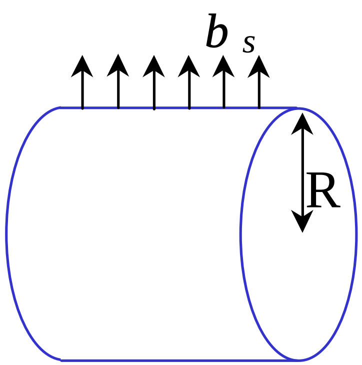
Indication of strong radial flow but things appear to be more complex at RHIC than SPS

Depends on fit range



Courtesy of M. Kaneta

m_T distribution from Hydrodynamics type model



$$E\frac{d^3n}{dp^3} \propto \int_\sigma e^{-(u^\nu p_\nu)/T_{th}} p^\lambda d\sigma_\lambda$$

$$u^n(t,r,z=0) = (\cosh r, \vec{e}_r \sinh r, 0)$$

$$r = \tanh^{-1} b_r \qquad b_r = b_s\, f(r)$$

$$\frac{dn}{m_T dm_T} \propto \int_0^R r\, dr\, m_T K_1\left(\frac{m_T \cosh\rho}{T_{th}}\right) I_0\left(\frac{p_T \sinh\rho}{T_{th}}\right)$$

Ref. : E.Schnedermann et al, PRC48 (1993) 2462

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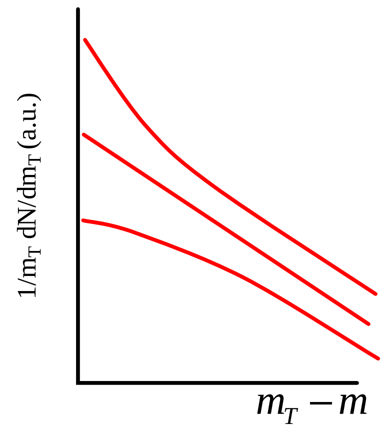
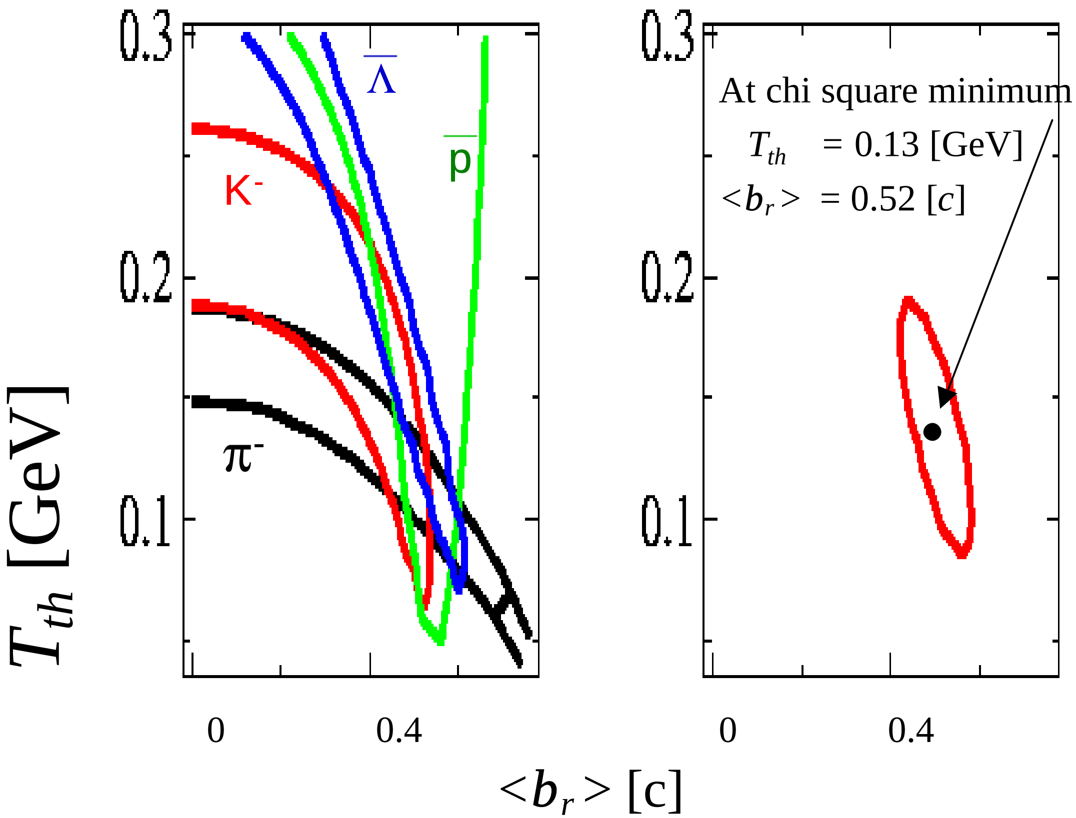
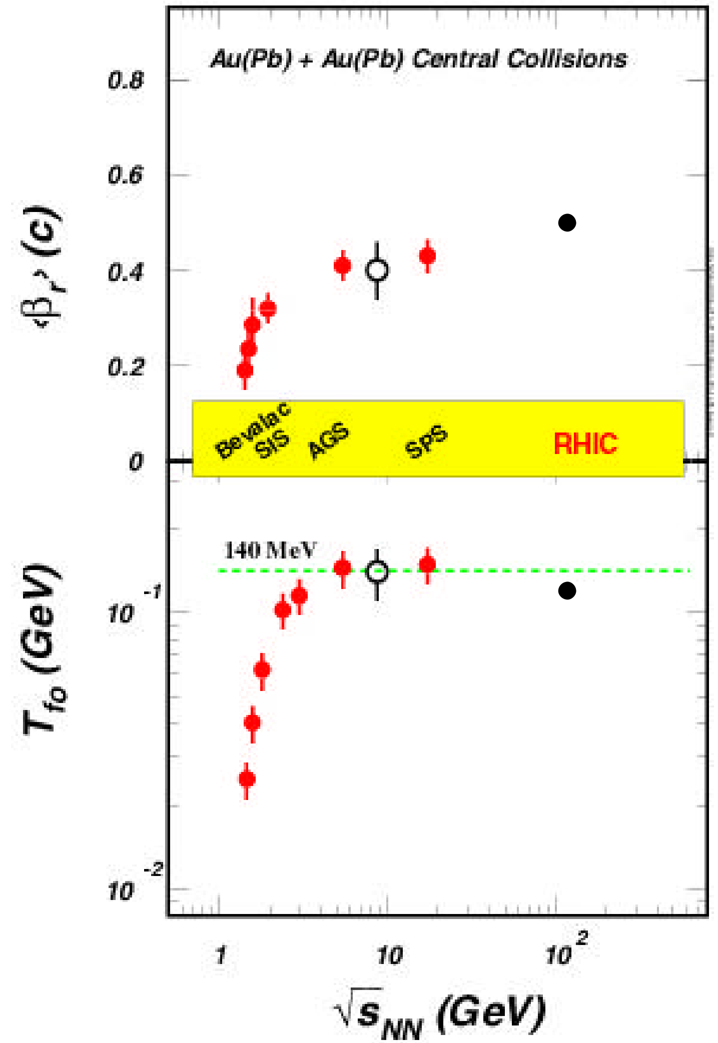
flow profile selected

$$\left(b_r = b_s (r/R_{max})^{0.5}\right)$$



χ^2 map (contour plot for 95.5%CL)





⇒ Strong radial flow at RHIC

β_r (RHIC) = 0.52c

T_{fo} (RHIC) = 0.13 GeV

explosive radial expansion at RHIC ⇒ high pressure

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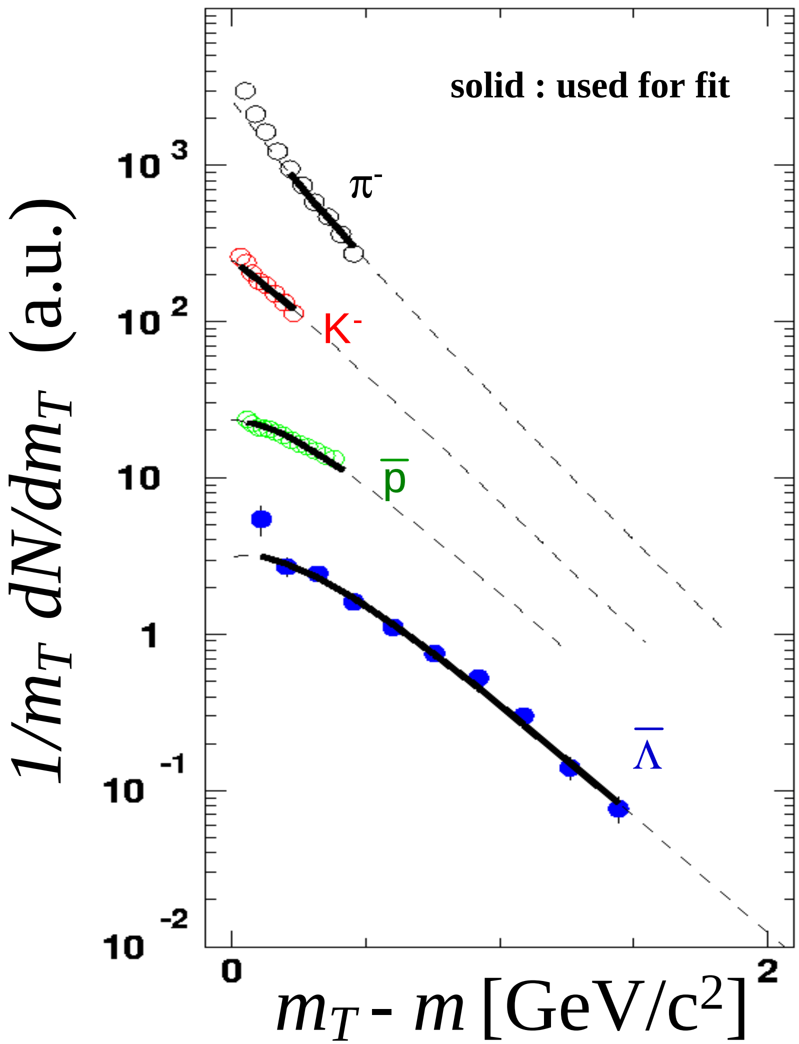
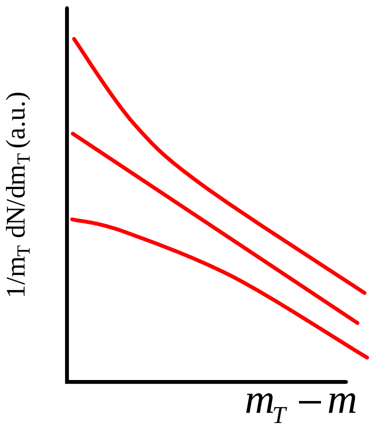
m_T distributions: data and model predictions

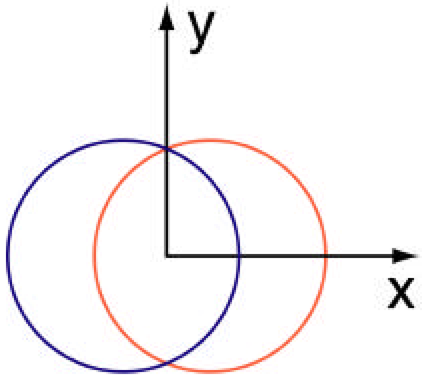


The bend is changing with particle mass

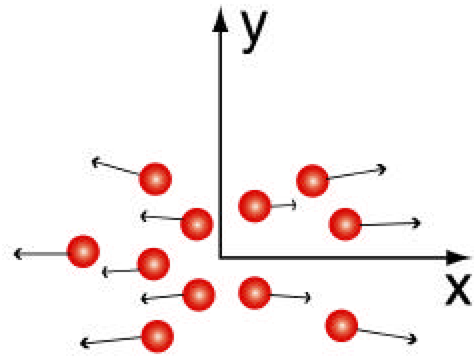


Elliptic Flow: A schematic view of v_2

$$e = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$



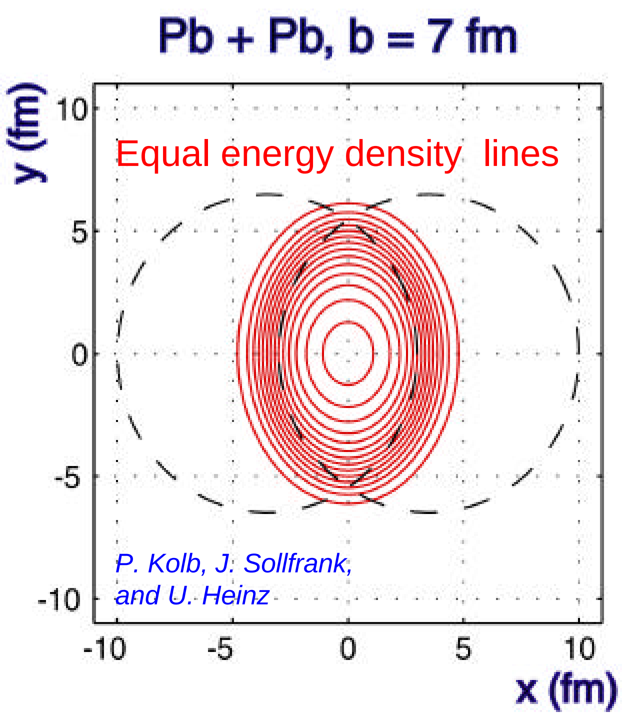
spatial anisotropy →

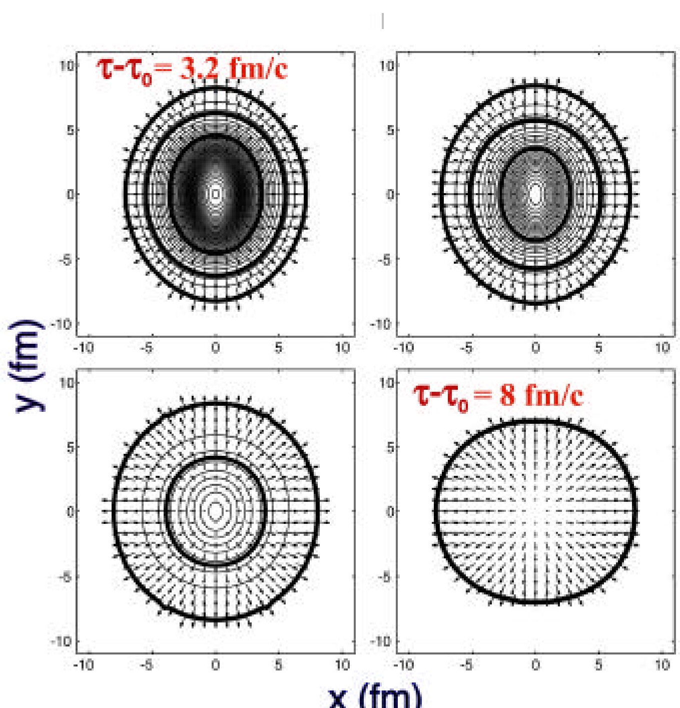


momentum anisotropy

$$v_2 = \langle \cos 2f \rangle$$

$$f = \mathrm{atan}\frac{p_y}{p_x}$$





v_2: 2nd harmonic Fourier coefficient in dN/dϕ with respect to the reaction plane

Elliptic flow observable sensitive to early evolution of system

Large v_2 is an indication of early thermalization

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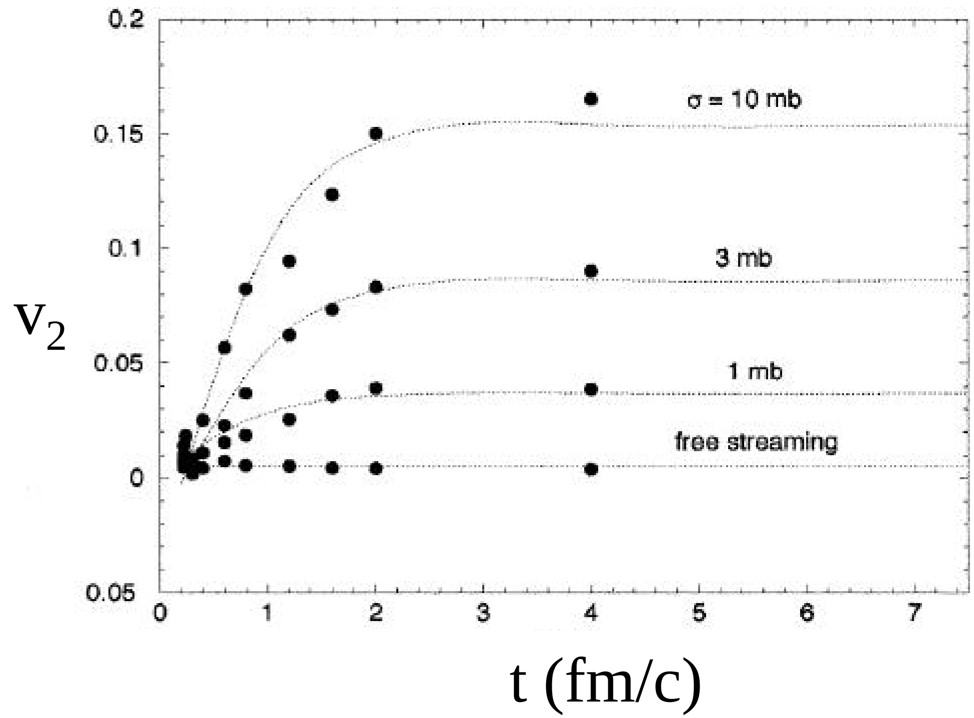
Elliptic flow and thermalization

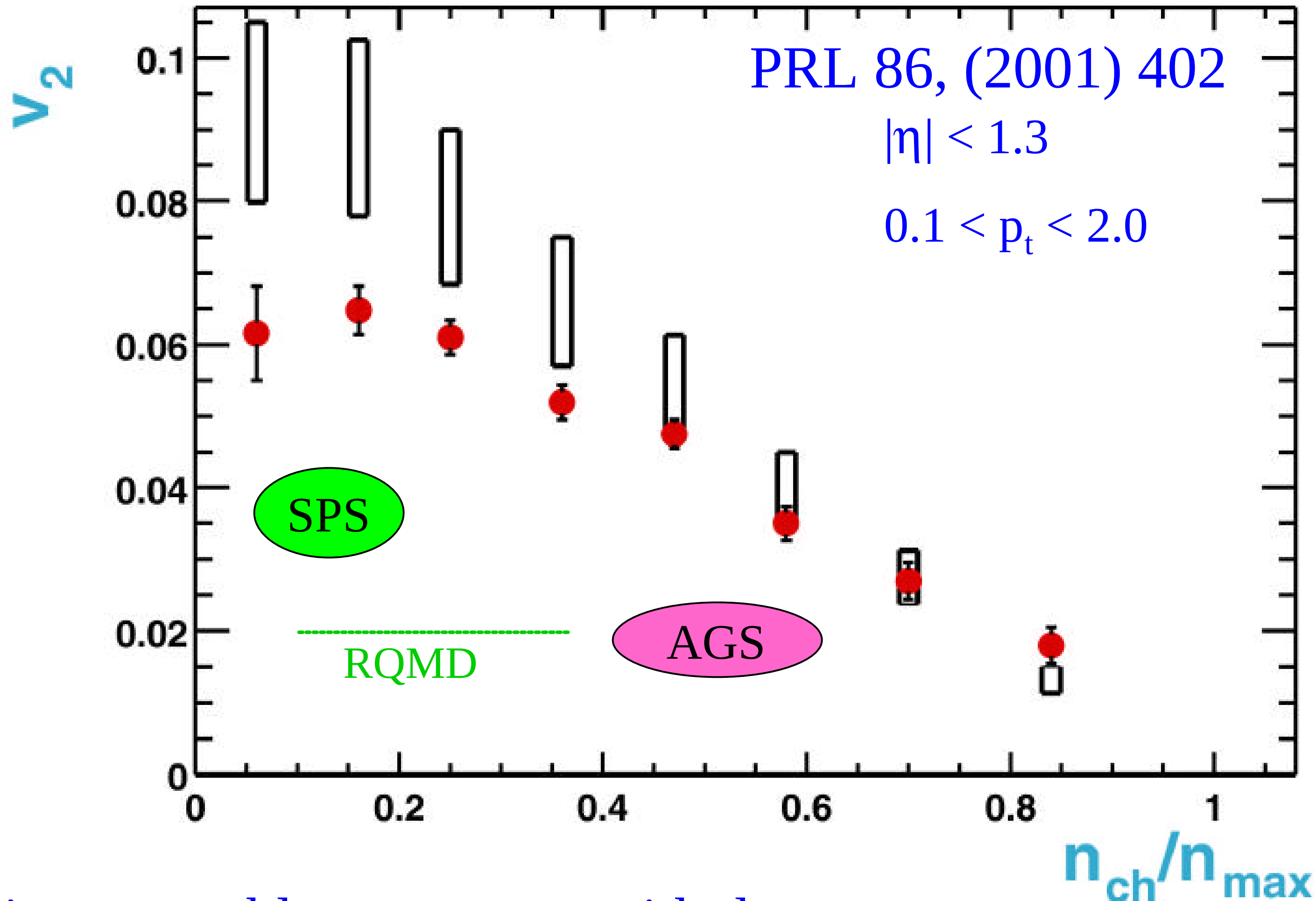
Zhang, Gyulassy, Ko, PL B455 (1999) 45

- Rescattering
  - Converts space anisotropy to momentum anisotropy
- Becomes more spherical
  - Self-quenching
    - ✓ thermalization at Early time



Charged particle v_2 versus centrality

Boxes show "initial spatial anisotropy" ε scaled by 0.19-0.25



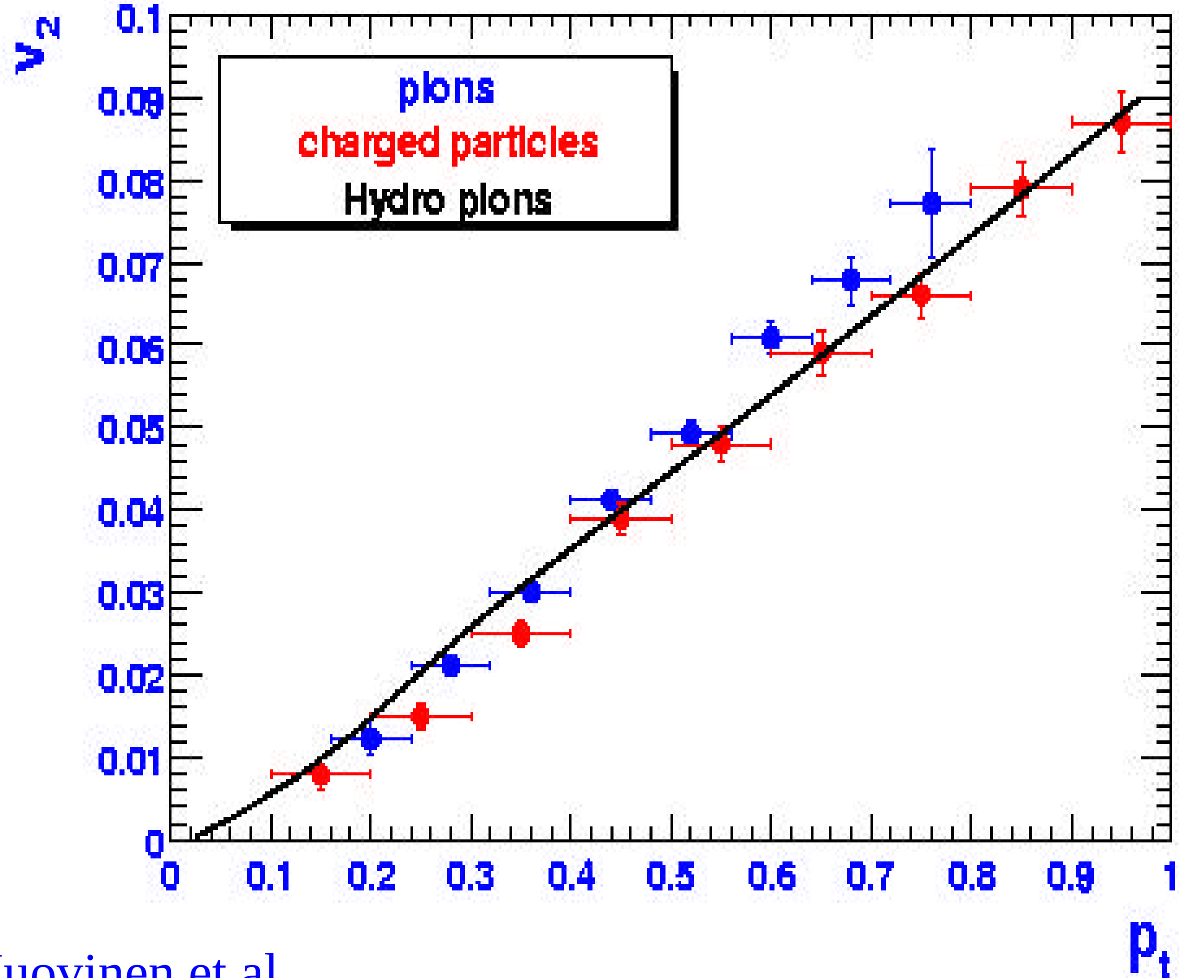
- Hydro-picture in reasonable agreement with data
    - compatible with early equilibration

Charged particle and charged pion $v_2(p_t)$ (minimum bias)

v_2 and $v'_2 = 0$ for $p_T=0$

- v_2 proportional to p_T

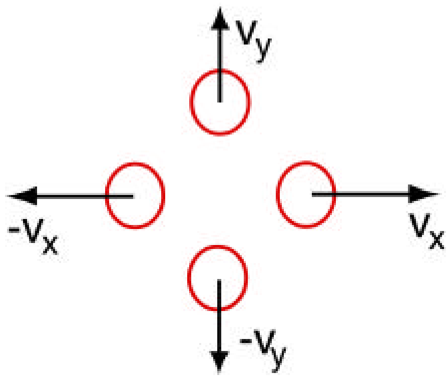
- Pions almost identical to h- but not exact



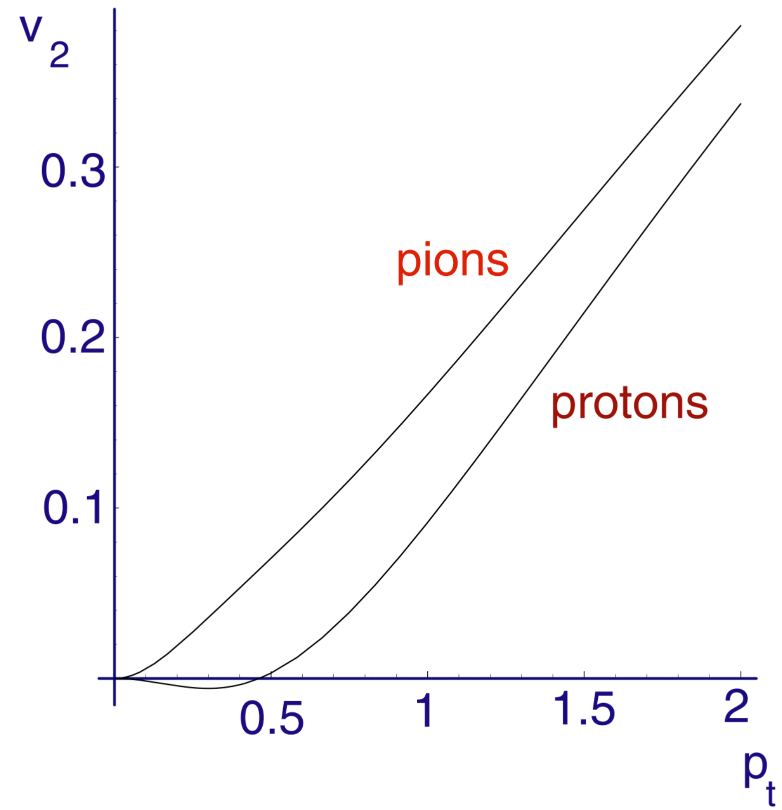
Hydro calculations: P. Huovinen et al.

$v_2(p_t)$ for a thermal source

Simple thermal source



$$v_2(m) = \frac{C_1 - e^{l\sqrt{m^2+p^2}}C_2}{C_3 + e^{l\sqrt{m^2+p^2}}C_4}$$



Pasi Huovinen

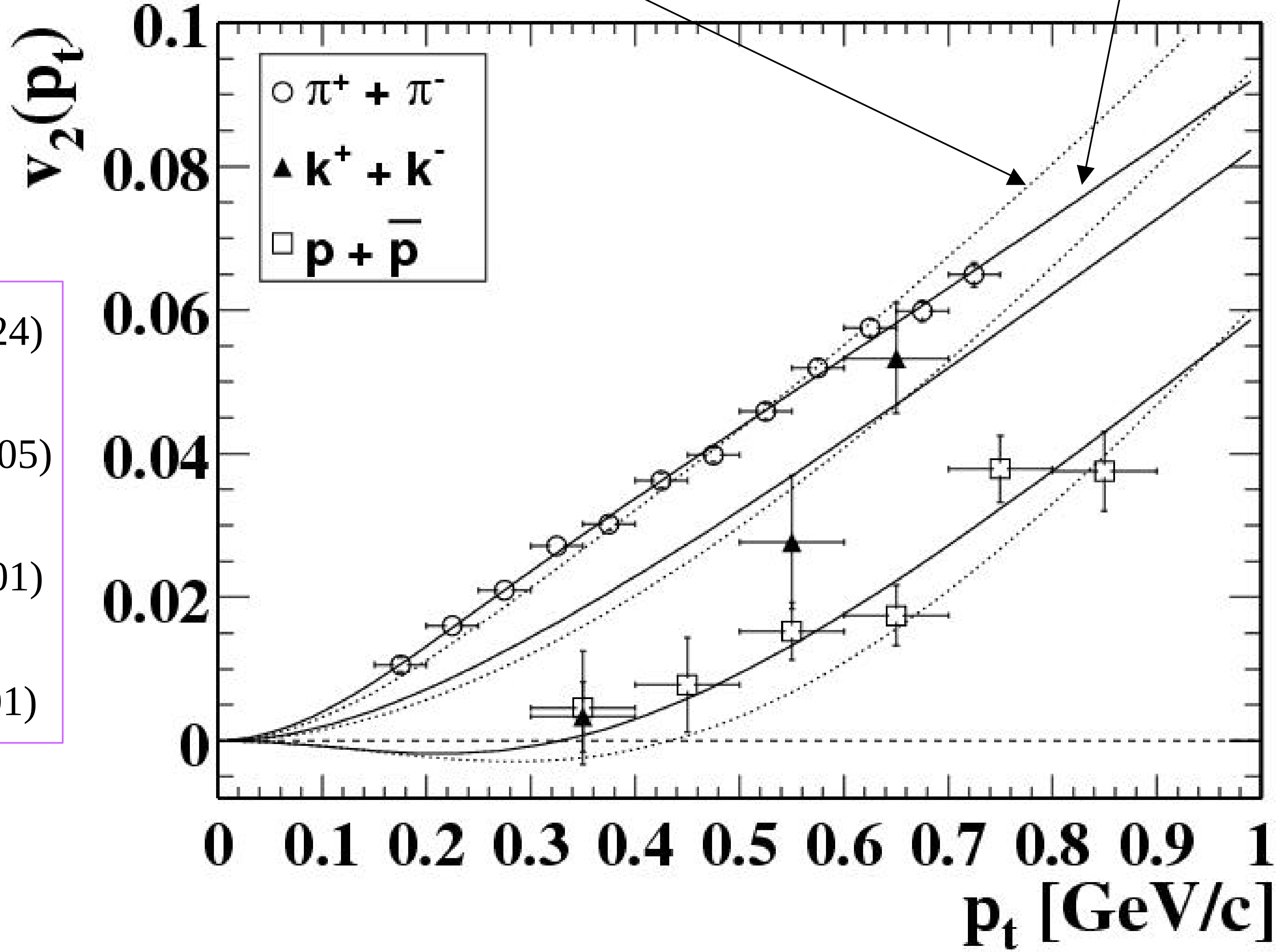
Flow for different species (min. bias)

$$v_2(p_T) = \frac{\int d\phi_b \cos(2\phi_b) I_2(\alpha(\phi_b)) K_1(\beta(\phi_b)) \left(1 + 2 s_2 \cos(2\phi_b)\right)}{\int d\phi_b I_2(\alpha(\phi_b)) K_1(\beta(\phi_b)) \left(1 + 2 s_2 \cos(2\phi_b)\right)}$$

$\alpha,\beta = f(\rho, T)$

$\rho = \rho_0 + \rho_a \cos(2\phi)$

T	135(20)	100(24)
ρ_0	.58(.03)	.61(.05)
ρ_a	.09(.02)	.04(.01)
S_2	0.0	.04(.01)



Summary

- Exploitation/detailed understanding of STAR Y-1 capabilities (centrality, PID, efficiency) allow clear physics statements [point is LOTS OF WORK]
- m, p_T, ϕ systematics of particle spectra reveal collective, thermal components
  - Emergence of consistent picture
- Building towards a consistent picture – Spectra
  - dN/dη justifies 2D approach – focus on transverse degrees of freedom
  - $\langle p_T \rangle_{HI}$ » $\langle p_T \rangle_{pp}$
  - Harder spectra for heavy particles

  collective flow from *rescattering*
  - BUT – “T vs m plot” misleading at best
  - Hydro-inspríred blast model: consistent fit to spectral shapes
    - T=130 MeV, β=0.52
- Building towards a consistent picture – anisotropic flow
  - v_2 – result of rescattering in *early* phase of collision
  - For the first time, hydro model describes $v_2(p_T,m,mult)$ almost quantitatively
  - Detailed study reveals *new* feature of freeze-out anisotropy

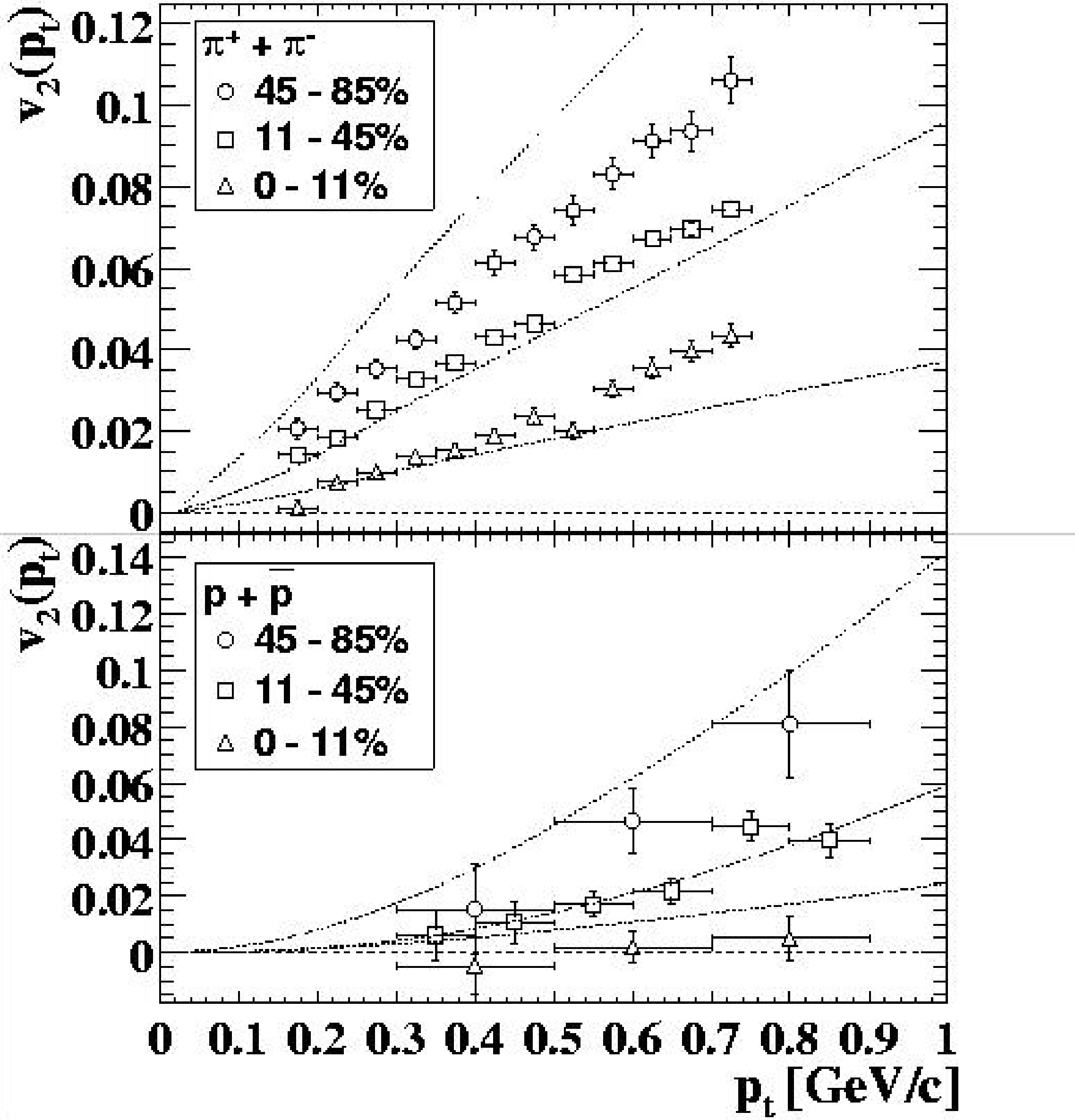
THE END

SPARE STUFF-not shown

Charged pion $v_2(p_t)$ for different centralities

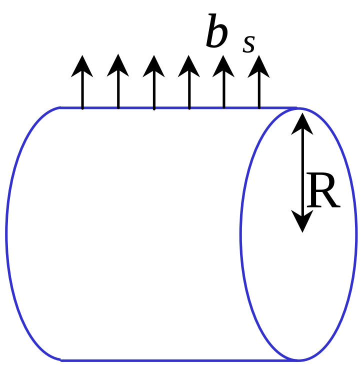
Examining in detail the discrepancy between hydro and data (mostly at peripheral events)

It appears to be species and/or pt independent



Courtesy of M.Kaneta

m_T distribution from Hydrodynamics type model



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$$u^n(t, r, z=0) = (\cosh r, \vec{e}_r \sinh r, 0)$$

$$r = \tanh^{-1} b_r \qquad b_r = b_s\ f(r)$$

$$\frac{dn}{m_T dm_T} \propto \int_0^R r\, dr\, m_T K_1\left(\frac{m_T \cosh\rho}{T_{th}}\right) I_0\left(\frac{p_T \sinh\rho}{T_{th}}\right)$$

Ref. : E.Schnedermann et al, PRC48 (1993) 2462

Approximation (Do not use for wide range fit!)

Ref.: I.G.Bearden et al (NA44), PRL78 2080 (1997)

Inverse slope parameter $= T_{th} + m < b_r >^2 \qquad (p_T \lesssim m)$

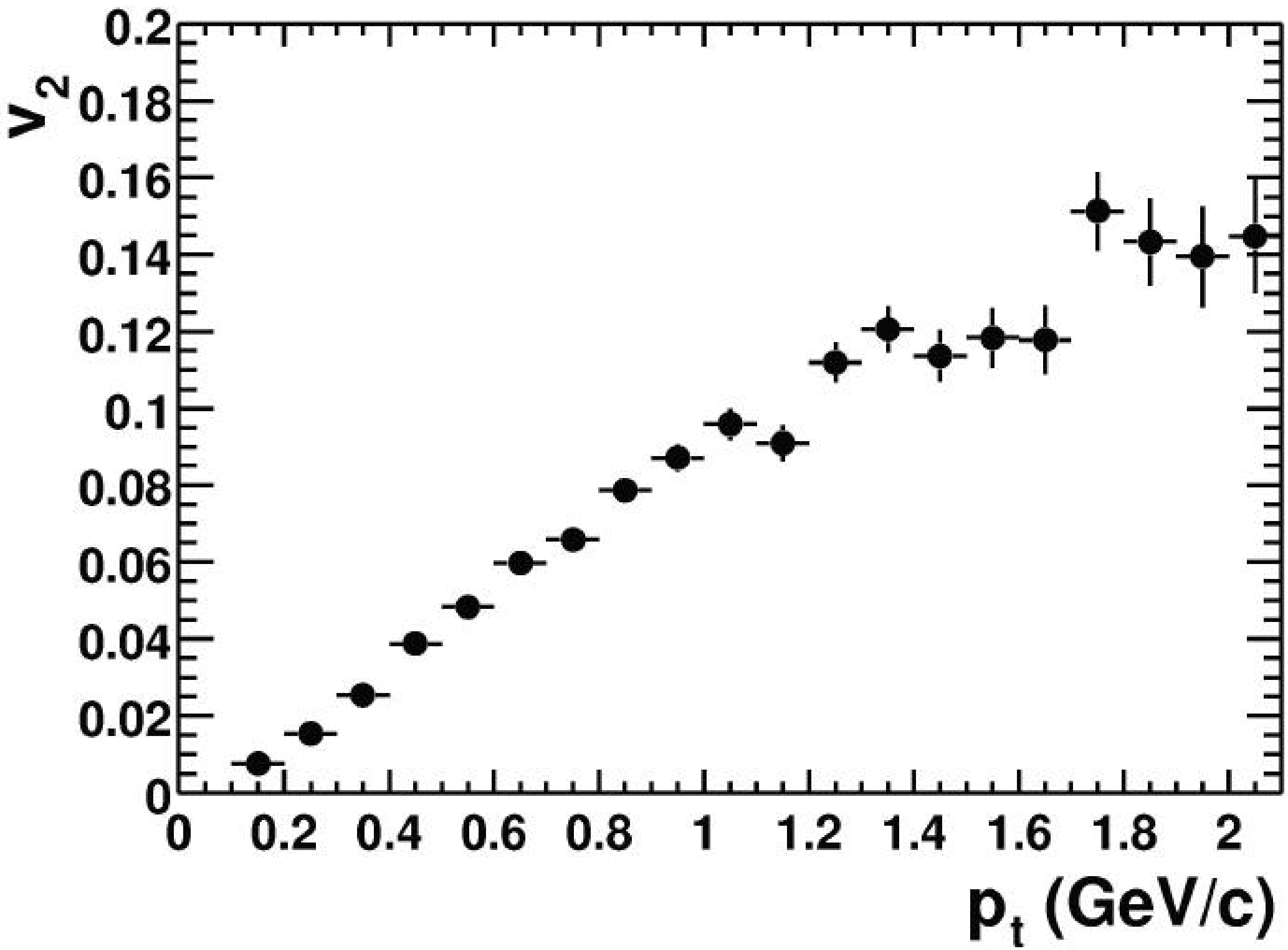
$$= T_{th}\sqrt{\frac{1+<b_r>}{1-<b_r>}} \qquad (p_T >> m)$$

Ref.: H.v. Gersdorff, QM1990 proceedings p.697c

flow profile selected

$\left(b_r = b_s (r/R_{max})^{0.5}\right)$

Pt dependence



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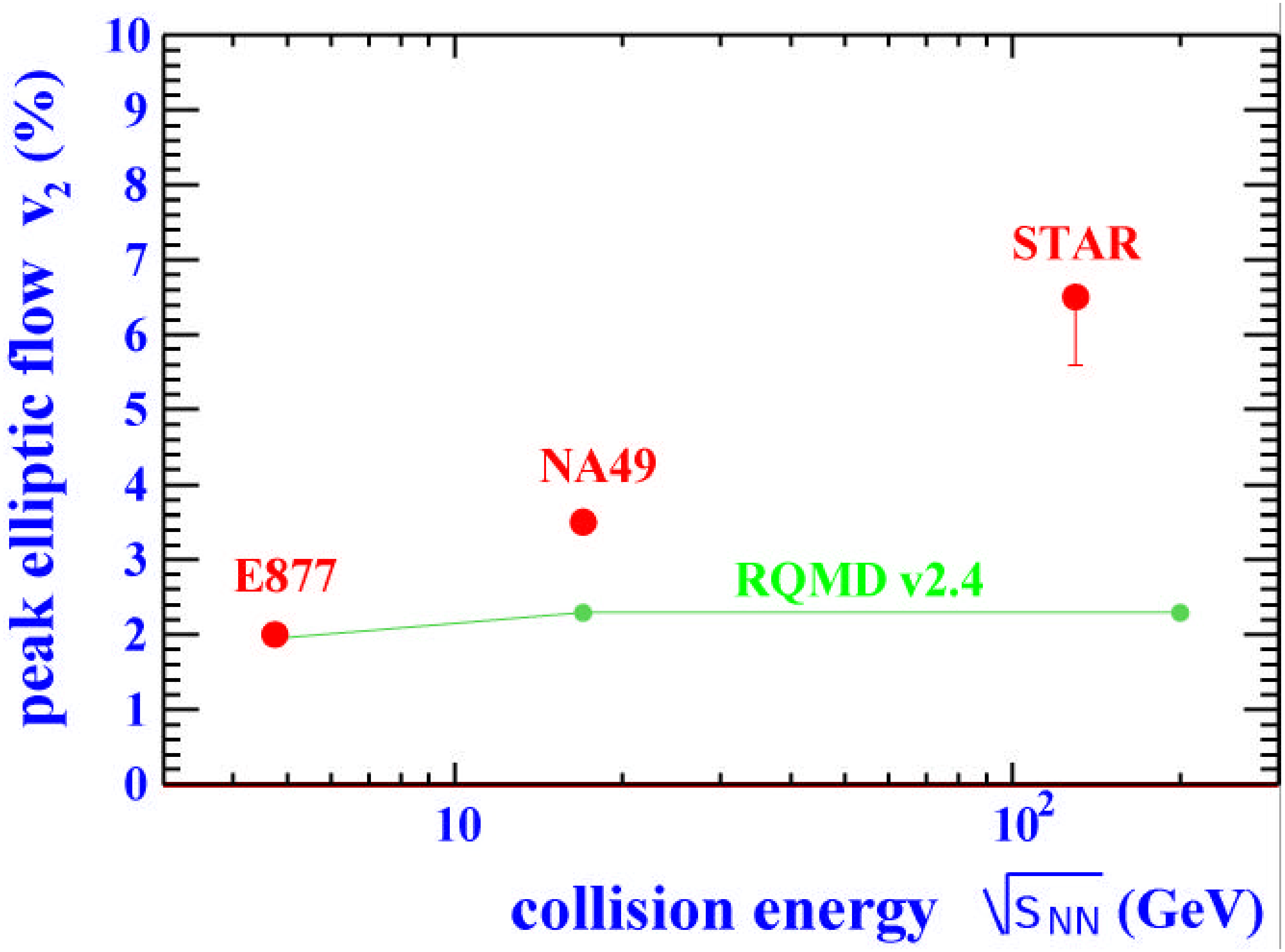
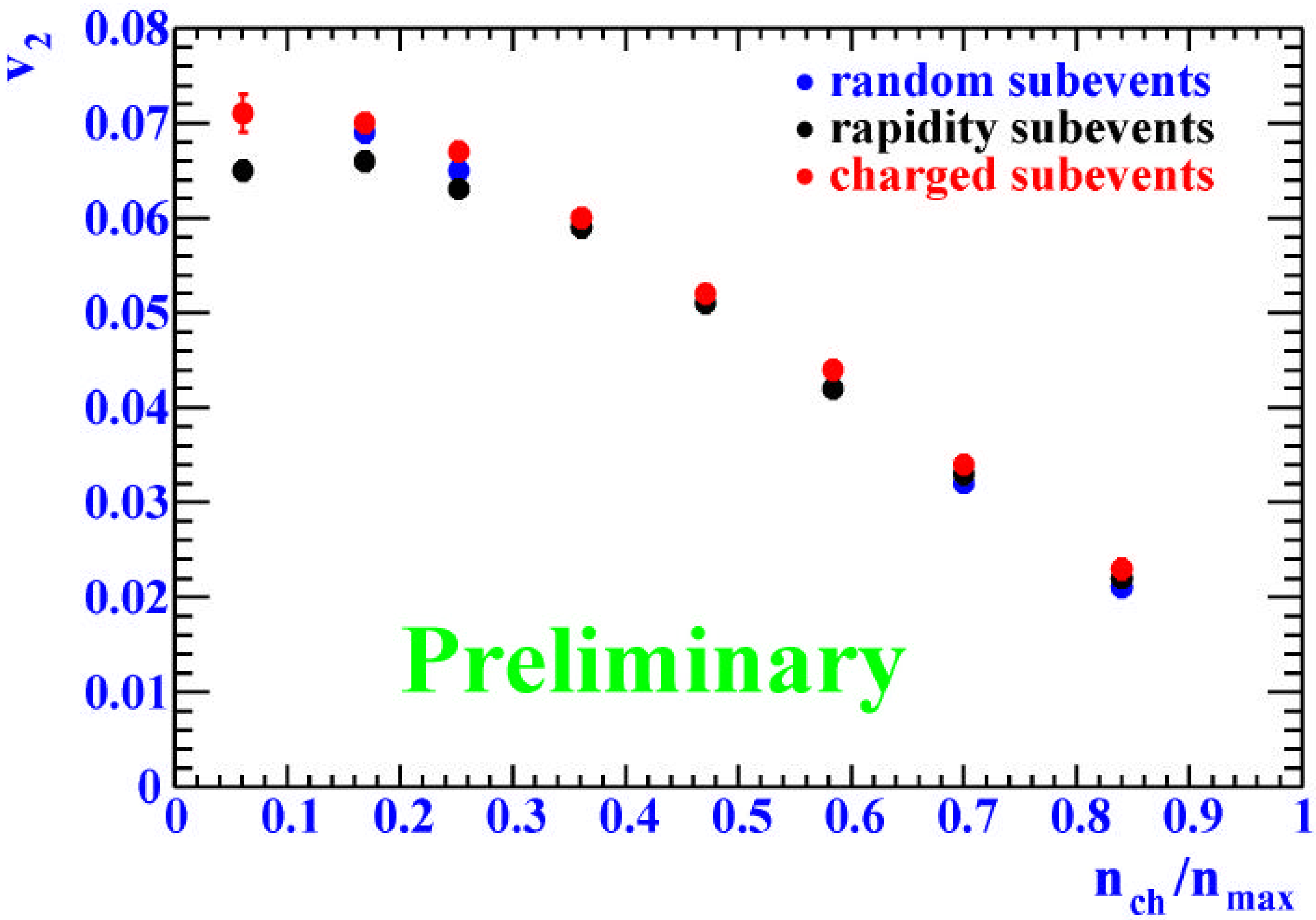
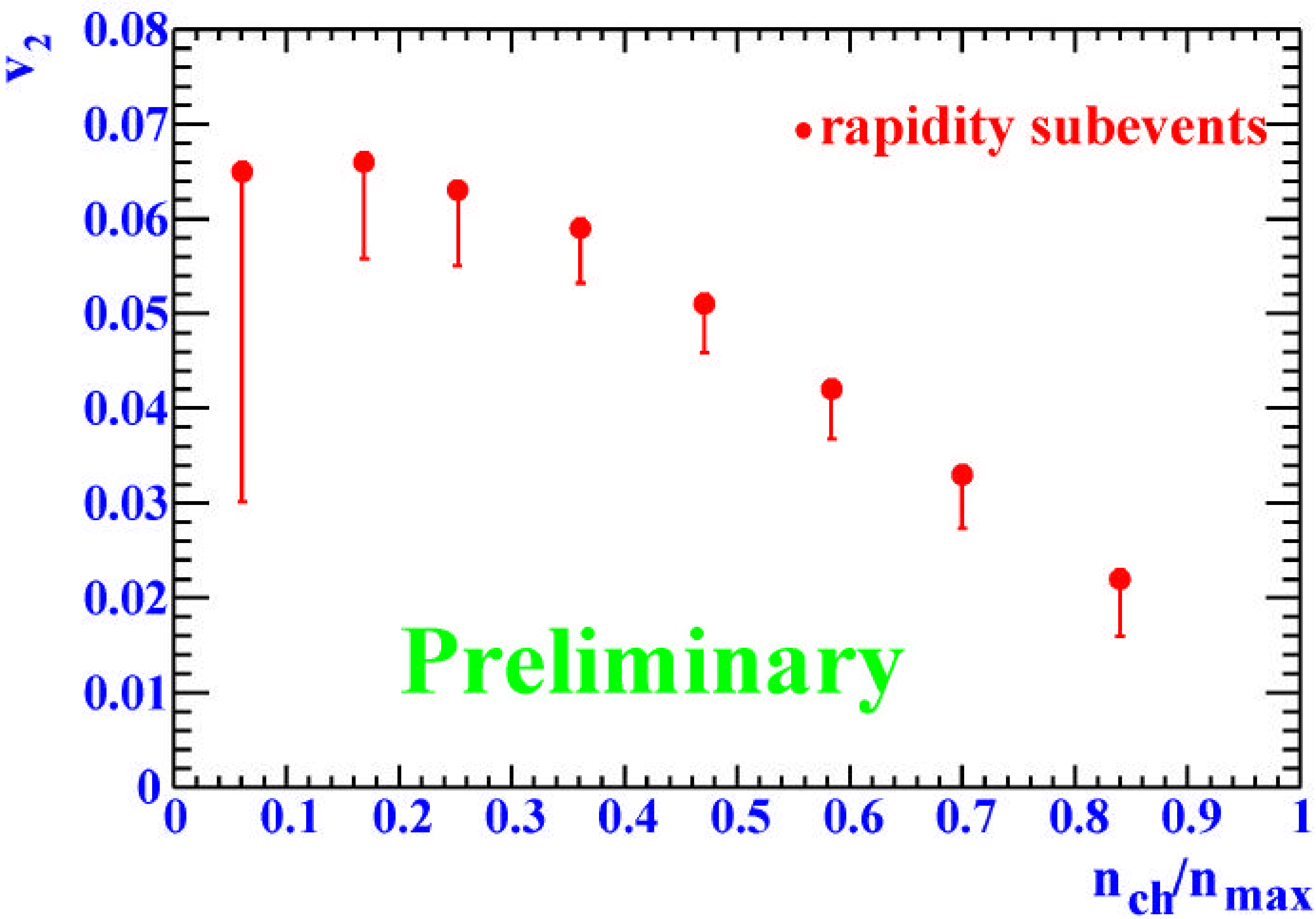
Excitation function



Different “sub event” methods

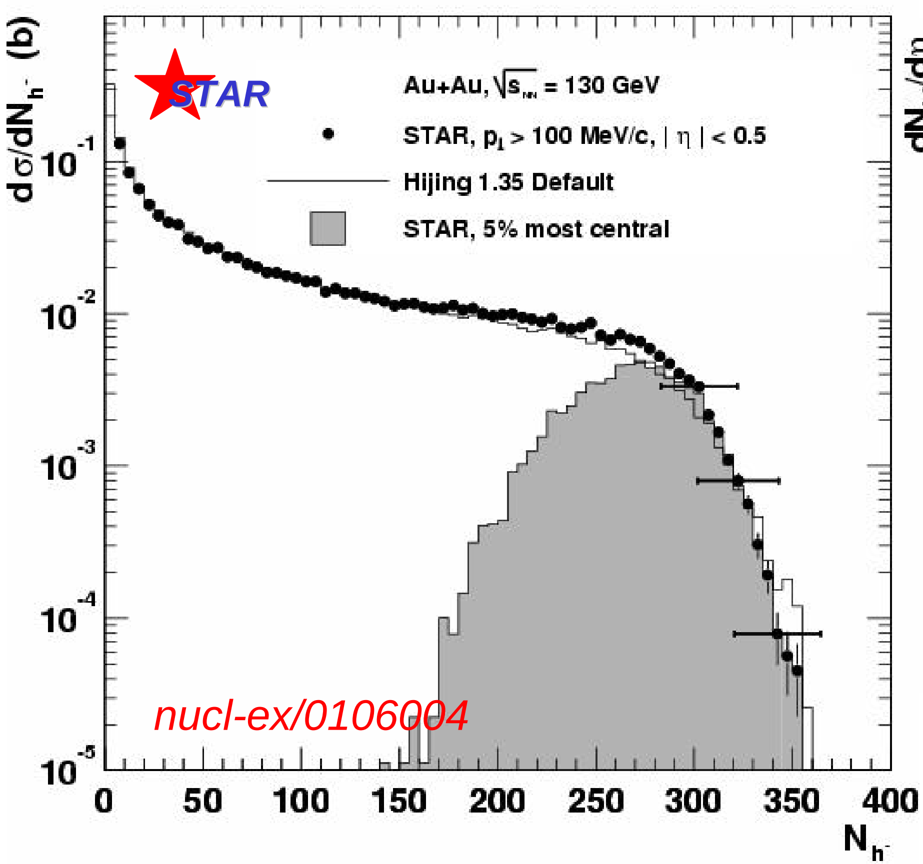


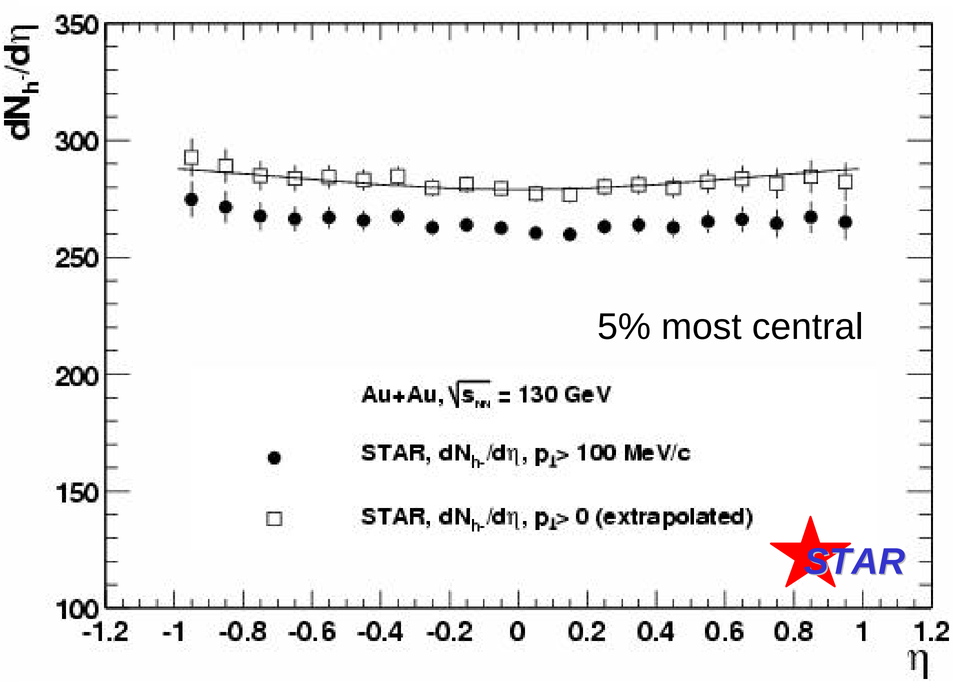
Systematic errors



h-

Central Rapidity Region: Charged Multiplicity in Au+Au at $\sqrt{s_{NN}}$ = 130 GeV





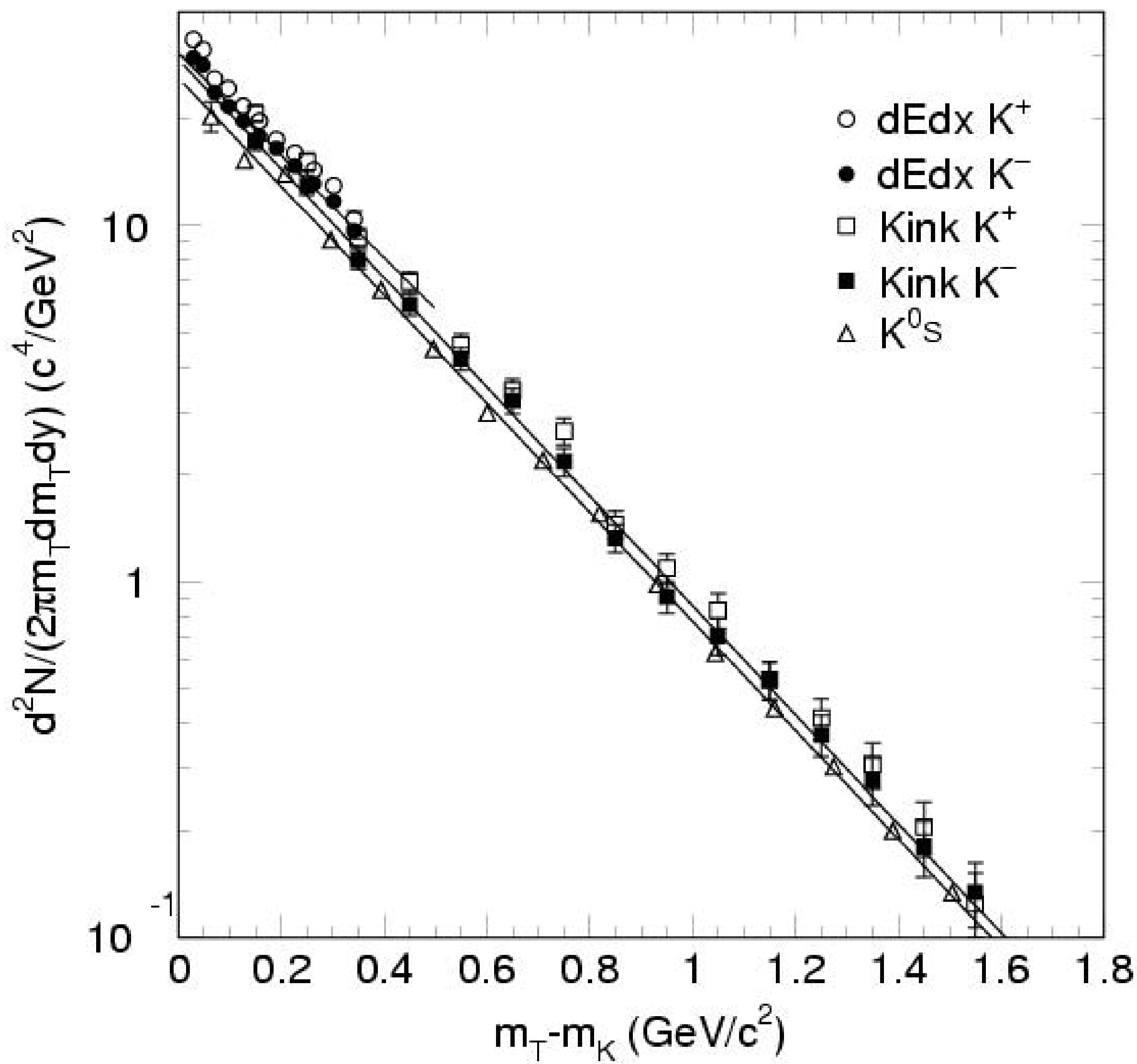
Corrected for decay feeddown: HIJING1.35
Multiplicity Sys Error: 6%
5% most central via ZDC cut
Shape dominated by nuclear geometry

$dN_{h^-}/d\eta|_{\eta=0}$ = 280±1±20
$dN_{ch}/d\eta|_{\eta=0}$ = 567 ±1±38
Relative flat in η
38% up compared to pp
52% up compared to SPS

PHOBOS: 3% most central collisions
$<N_{ch}>$ = 4200 ± 470

Kaon slopes comparison

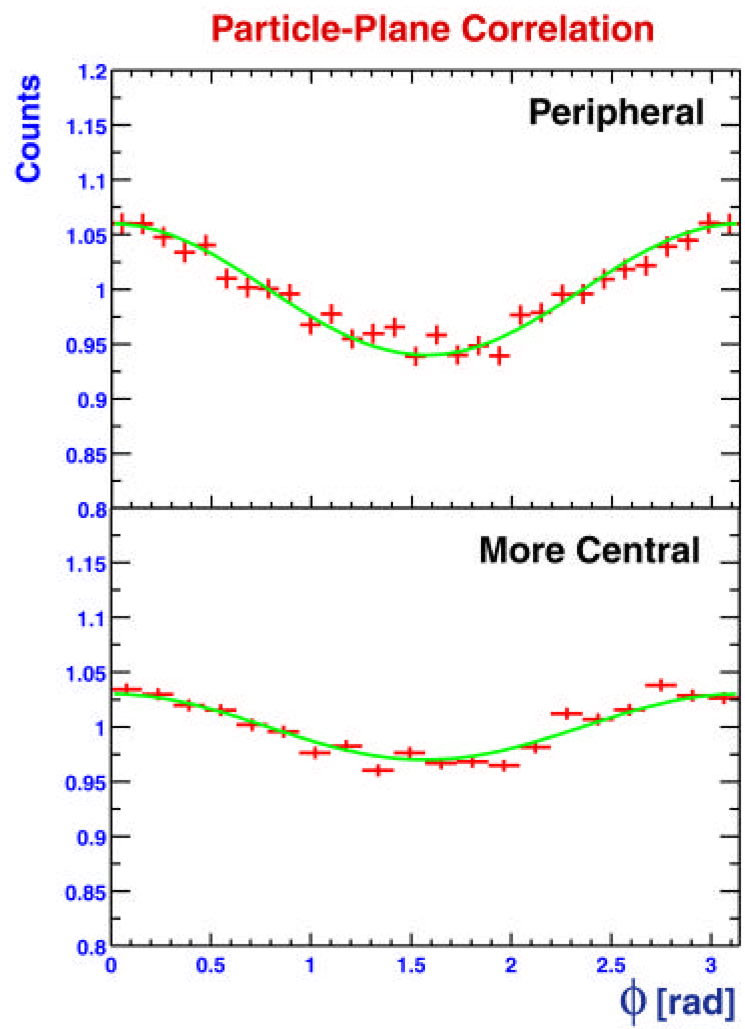
• All species have similar slopes



Azimuthal-angle distribution versus reaction plane

- v_2 increases from central to peripheral collisions

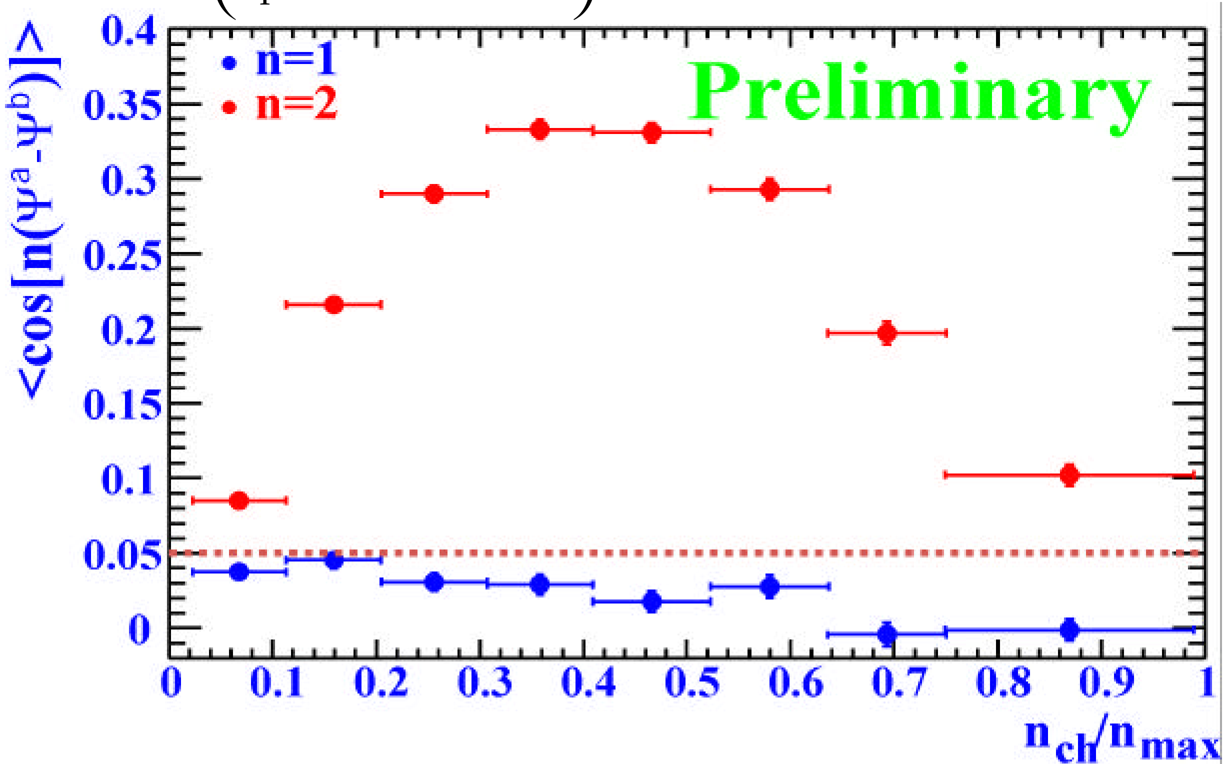
$$v_2 = \langle \cos 2f \rangle$$



Sub Event Correlation

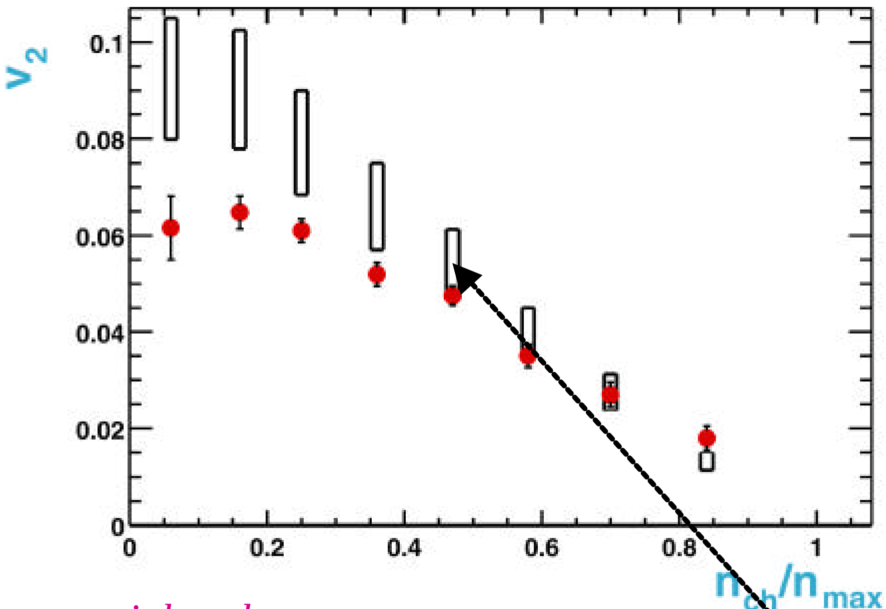
$$\Psi_2^{A,B} = \frac{1}{2}\mathrm{Tan}^{-1}\left(\frac{\sum_i w_i \cdot \sin(2\phi_i)}{\sum_i w_i \cdot \cos(2\phi_i)}\right)$$

- Non-Flow Effects
  - Momentum conservation
  - HBT, Coulomb (final state)
  - Resonance decays
  - Jets



Topic 5 cont'd: Elliptical Flow

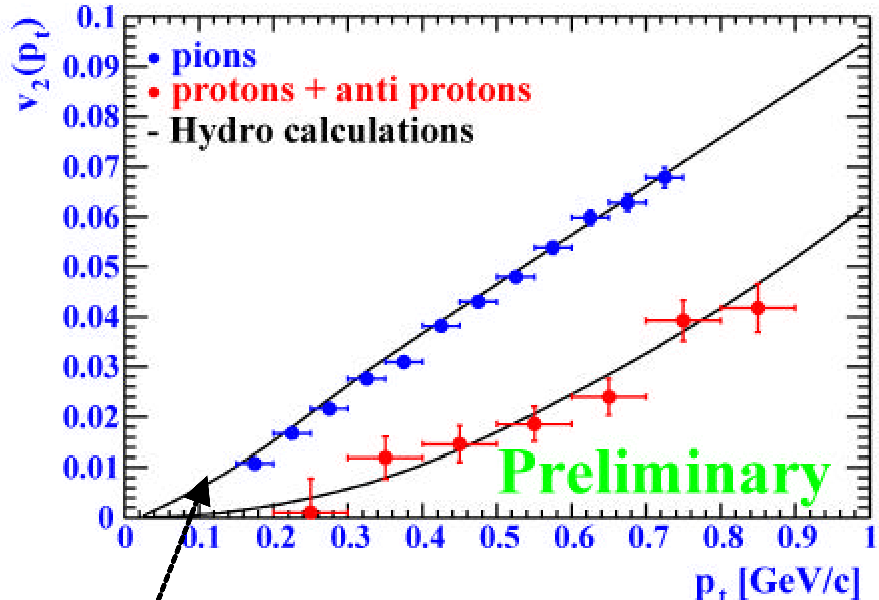
v2 vs centrality



peripheral

central

v2 vs p_T and particle mass

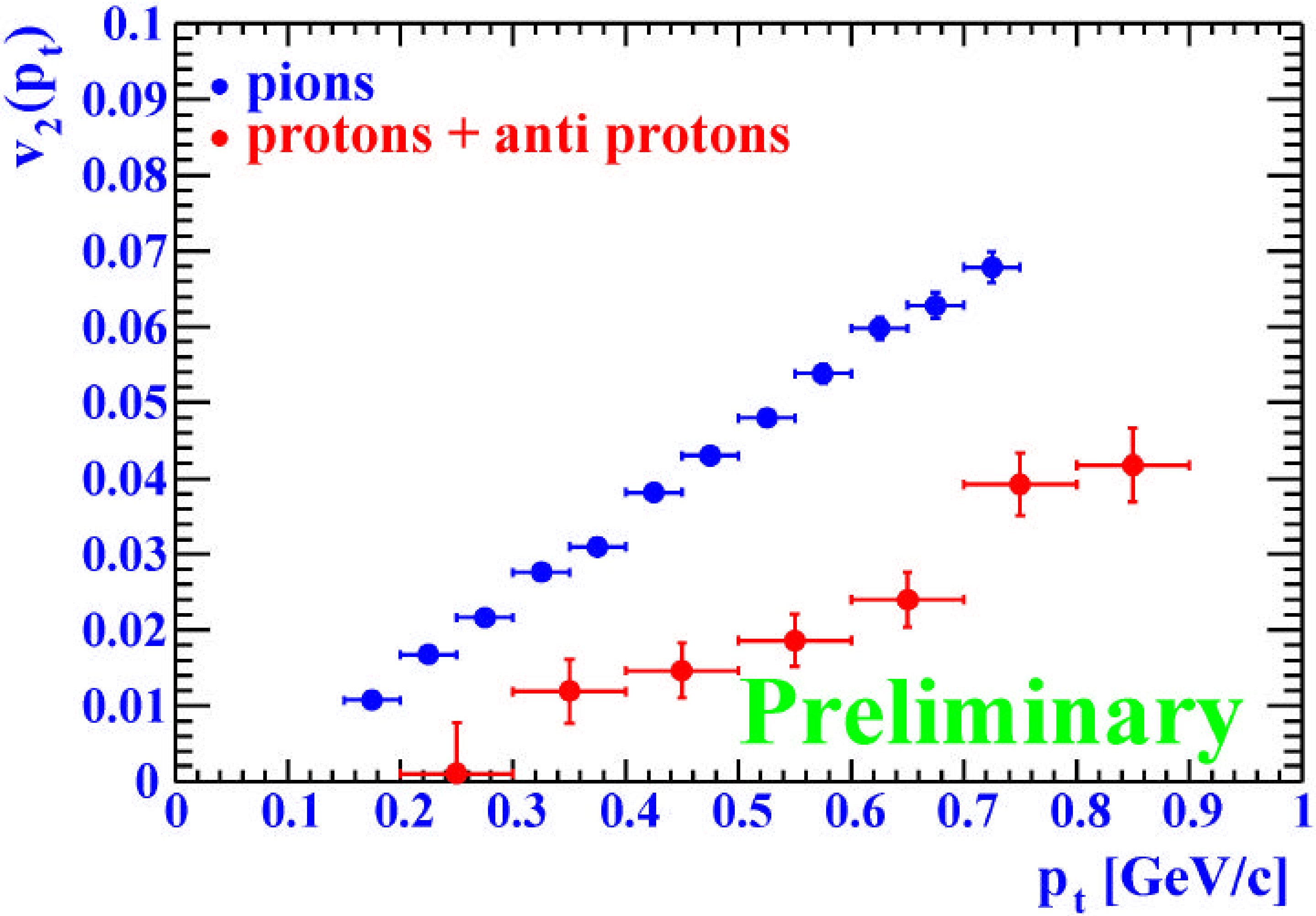


• Hydrodynamical calculations in reasonable agreement

⇒ compatible with early equilibration

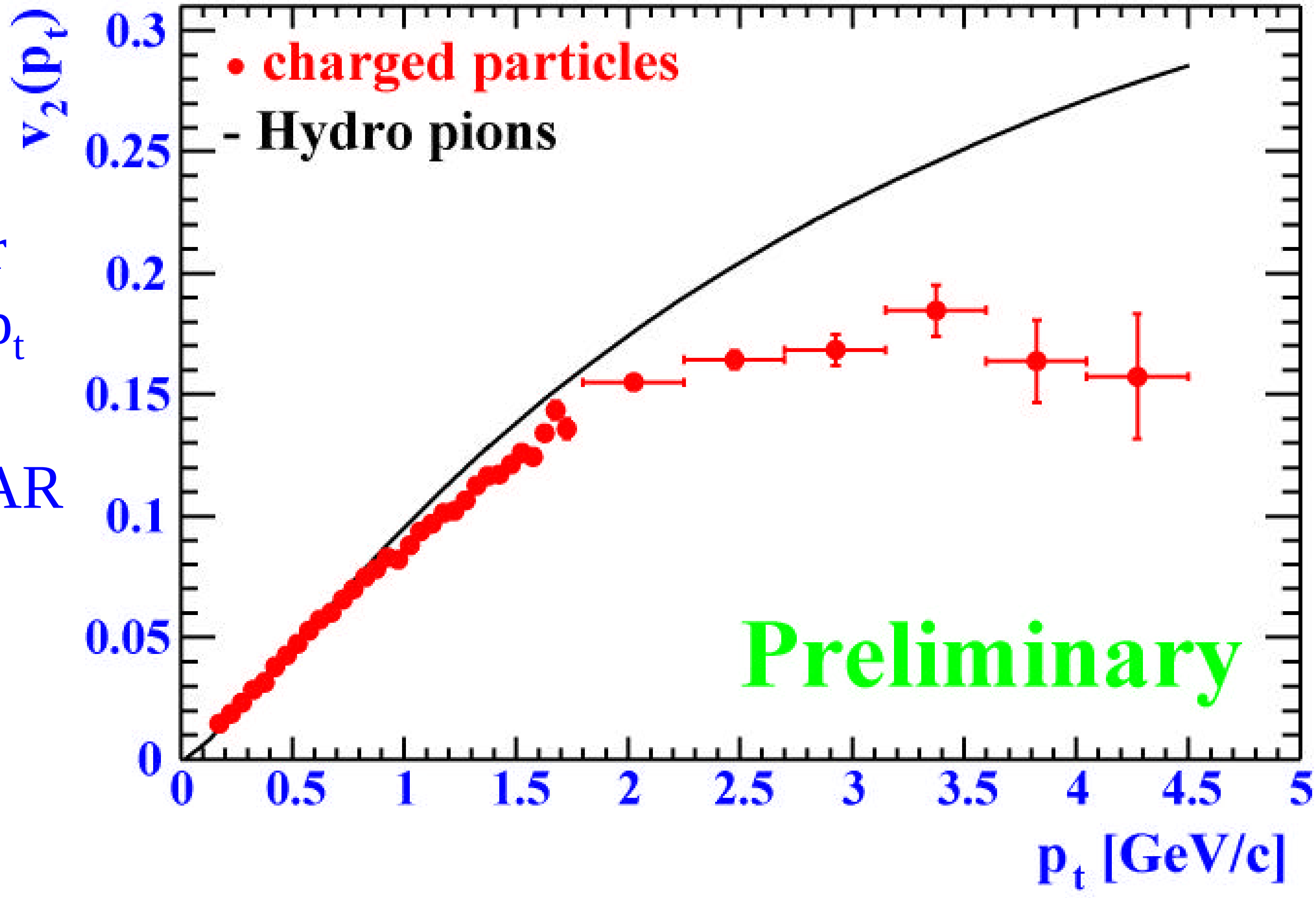
• Contrast to lower energies where hydro overpredicts elliptical flow

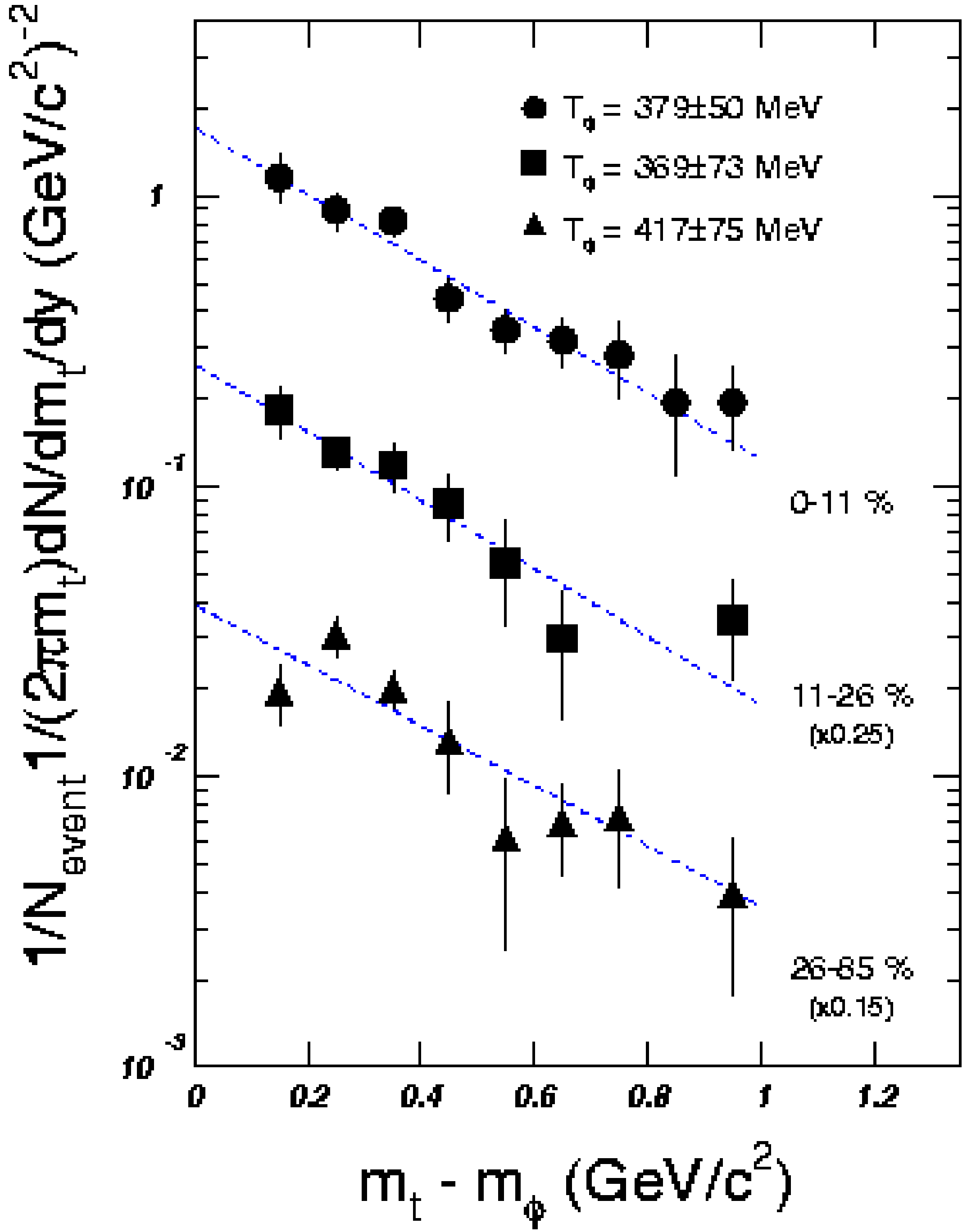
Charged pion and proton + anti proton $v_2(p_t)$ (minimum bias)



Charged particle anisotropy
$0 < p_t < 4.5$ GeV/c

- Only statistical errors
- Systematic error 10% - 20% for $p_t = 2 – 4.5$ GeV/c
- More in the STAR high-pt talk (James Dunlop, PS2, this afternoon)





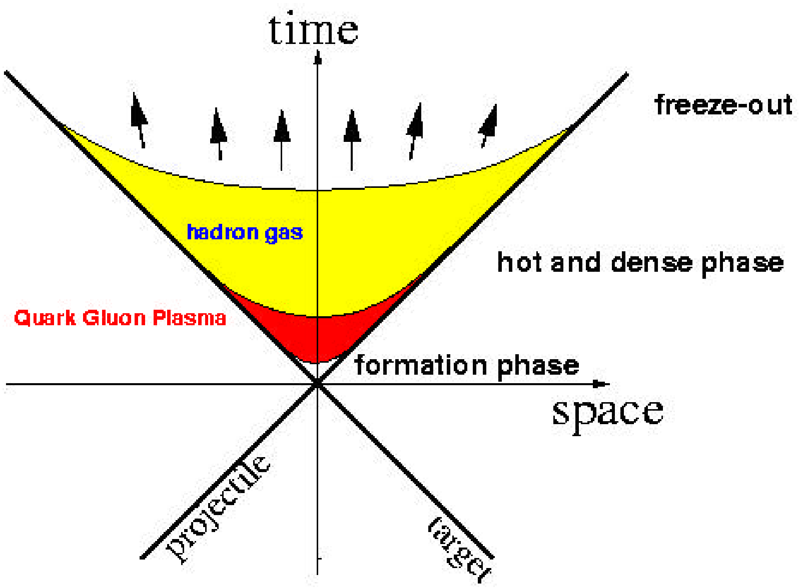
T_ϕ = 379±50 MeV
T_ϕ = 369±73 MeV
T_ϕ = 417±75 MeV
0-11 %
11-26 %
(x0.25)
26-85 %
(x0.15)
$1/N_{event}\,1/(2\pi m_t)dN/dm_t/dy\ (GeV/c^2)^{-2}$
$m_t - m_\phi\ (GeV/c^2)$
1
10^{-1}
10^{-2}
10^{-3}
0
0.2
0.4
0.6
0.8
1
1.2

Φ

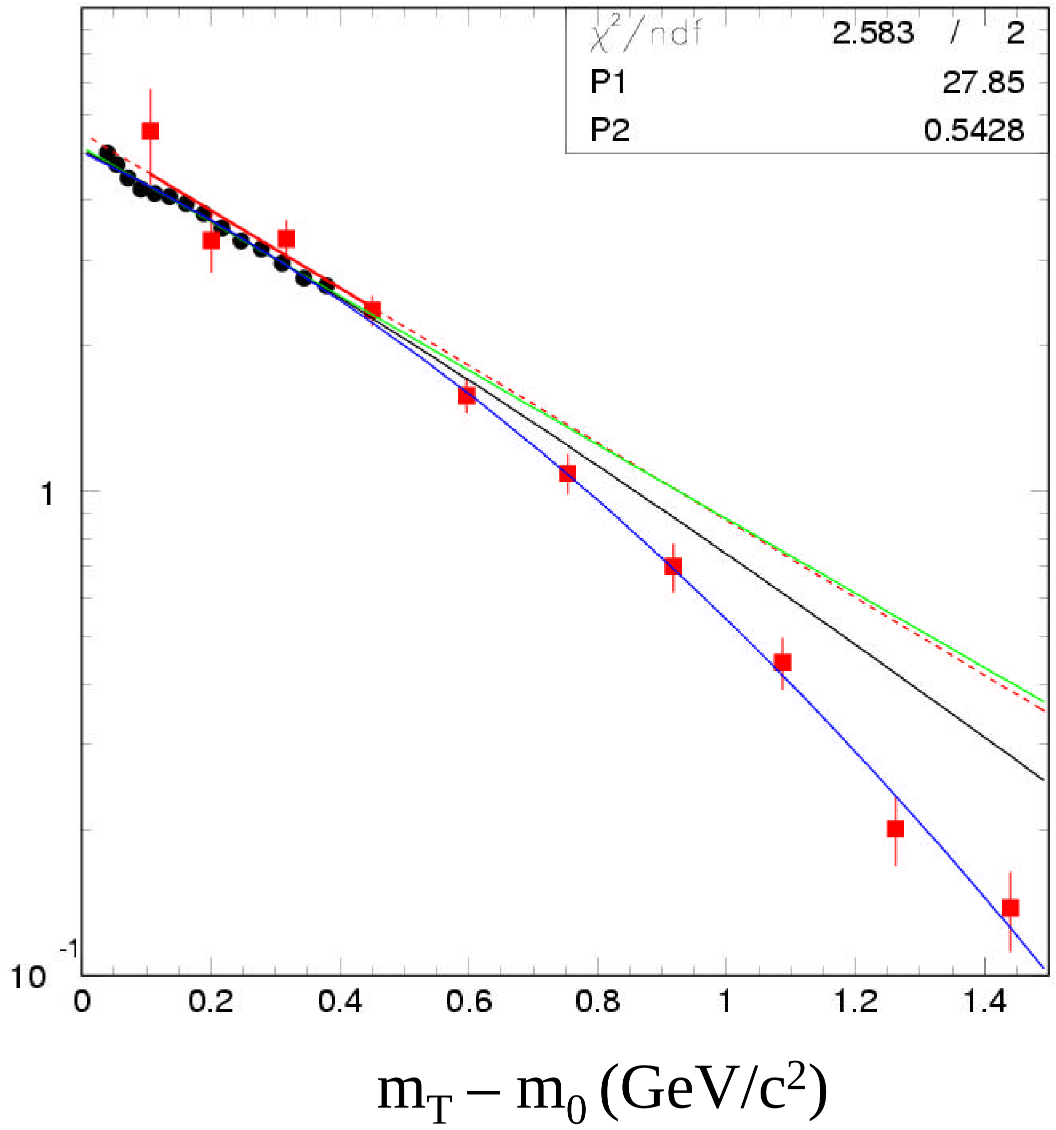
S T A R

Why Elliptic Flow Measurements?

- The pressure - The pressure gradient generates collective motion (flow)
  - Central collisions: radial flow
  - Peripheral collisions: radial flow and anisotropic flow



Antiproton vs anti-Lambda (x2)



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